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RESEARCH

Precision Nutrient Management Techniques to Bridge Maize and Rice Yield Gaps in Tikapur, Nepal

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ABSTRACT

Purpose: *The main objective was to evaluate the effectiveness of site-specific nutrient management (SSNM) practices to enhance productivity and reduce yield gaps in spring maize and rice in the Rani Jamara Kulariya Irrigation Project Command Area (RJKIPCA), Kailali, Nepal. Additionally, it sought to validate the NE®-Hybrid maize and rice models for predicting yields and profitability compared to traditional farmers' fertilizer practices (FFP).*

Research Method: *Nutrient Expert ®-Hybrid maize and Rice models embedded the household survey form of the NE-based questionnaire and the soil analysis of the farmers' field, the fertilizer rates and application timings were formulated by Nutrient Expert® Rice and maize before plantation. The sowing of spring maize for various SSNM practices at 42 fields (18 from both Tikapur and Janaki and 6 for Lamkichuha)] and Nutrient Omission Plot Technique (NOPT) trials at 21 fields in maize 9 from both Tikapur and Janaki and 3 from Lamkichuha. The nursery raising and transplanting of spring rice using SSNM approaches in 6 farmers field and NOPT approaches in three farmers field of Tikapur-7, Janaki-4 and Lamkichuha-7 was accomplished with a Randomized Block Design using diamond trials and farmers' fields as replications. R software was used for data analysis, including yield gap analysis and ANOVA.*

Findings and Values: *The results show a small variation (10-15%) between both observed grain production and farmers' income and the NE® model predictions, which supports the validity of the rice and maize models. Results show that majority of soil at the experiment site was deficient in N and K. Absence of P resulted in the least yield loss for both spring maize and rice. Farmer's fertilizer practices (FFP) led to declining yields, particularly among hybrid maize growers. The soils in Janaki and Tikapur were more likely to N and K deficiencies than those in Lamkichuha. The NE®-Hybrid maize and rice models effectively predicted yields and profitability, outperforming traditional farmer practices.*

Keywords: *NE®- Hybrid maize and rice, NOPT, Spring corn and rice, Yield gaps*

INTRODUCTION

In all of the areas of the *Rani Jamara Kulariya* Irrigation Project sites (RJKIS) command regions in *Kailali*, maize is third cereal crops that are grown in the spring (MOALD 2021, RJKIP 2020). Similar to this, a few areas are dominated by the cultivation of spring rice in *Tikapur-7 (Beluwa), Janaki-3 and 4 (Subarnapur and Munuwa),* and *Lamkichuha-7 (Hardahani)* (RJKIP 2019). The young forest soil in the project area has shown signs of multiple nutrient deficiencies, leading to a significant decline in the yields of major cereal crops such as main-

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season and spring rice, maize, and wheat in recent years. This has been attributed to the repeated cultivation of major cereals without leguminous crop rotation, as well as to the burning of crop residues (RJKIP 2019, Bist *et al.* 2021, Devkota *et al.* 2016, Pandey *et al.* 2017, Bajracharya *et al.* 2017). The Nepalese government (GoN) has been planning to transition from subsistence to commercial agriculture throughout the years.

As specified by the Sustainable Development Goals the GoN has planned to transition from traditional farming to modern commercial farming in order to ensure balanced human nutrition in a sustainable manner (Timsina *et al.* 2021). Based on the '4 R' principles—farmers should conduct a plant needs assessment prior to planting and nutrient supplements should be administered from an appropriate source at a suitable time and dosage. Site Specific nutrient management (SSNM) is an approach of feeding plants with nutrients as and when required. Optimal SSNM strategies can help Nepalese farmers grow crops according to their best practices (Anand *et al.* 2017, Bruulselma *et al.* 2012, Dobermann *et al.* 2004, Pampolino *et al.* 2021). Farmers adopting NE-based nutrient recommendations for major cereals have shown improved yields, profitability, and reduced negative effects in several studies conducted in eastern and central Nepal (Bogati *et al.* 2021, IPNI 2019, Timsina *et al.* 2022) and India (Sapkota *et al.* 2021, Majumdar *et al.* 2017).

Nutrient Expert® (NE), a decision-support system grounded in site-specific nutrient management (SSNM) principles, has been tested and implemented across several Asian and African countries as a novel recommendation approach for managing nutrients in selected crops, such as rice. The Nutrient Expert (NE) model is developed using after the estimation of various fertilizer use efficiencies based on indigenous nutrient supplying capacity of soil (IPNI 2017). The correlation results between the NPK analysis through soil test and based on nutrient omission plot techniques (NOPT) based field experimentations were analyzed with the several questionnaires embedded in the software while formulating the NE- Rice, maize and Wheat models (Dobermann *et al.* 2004). This model attempts to analyze the maximum attainable yield over the farmer's practices and several varieties/cultivars of rice, maize and wheat have been tested based on QUEFT model (Majumdar *et al.* 2017). The governmental recommendation of NPK fertilizer as a blanket application for the entire country is a generalized approach, wherein there would be the higher chances of overuse or deficit use of the fertilizer and it makes the environmental pollution too. NE- Rice, and maize developed as per the inclusion with the estimation of indigenous nutrient supplying capacity and target yield approach would give the balanced fertilization with economic profit (Timsina *et al.* 2021).

While numerous studies have demonstrated the benefits of using NE® crop modeling to enhance resource use efficiency for major cereals eastern and central regions of Nepal (Timsina *et al.* 2021, Majumdar *et al.* 2017), limited research has been conducted in the Sudurpashchim Province. The objectives were to compare precision nutrient management technologies such as NE model with farmers' fertilizer practices in spring maize and rice and promote SSNM-based fertilizer management among farmers in the RJKIP irrigation areas, which ultimately increase crop yields, reduce production costs, boost farmer incomes, and enhance food security and livelihoods.

MATERIALS AND METHODS

Experiment sites choosing NE®-Modelling

Figure 1 shows the multi-locational on-site experiment (28050'99"N, 81033'33"E and 241.3 masl.) for growing NE®-Hybrid Maize, NE®-Rice and NOPT of spring maize and rice at all experimental sites in Tikapur, Janaki, and Lamkichuha's wards three, five, and seven, which have access to RJKIP irrigation.

Research indicates that the soil in *Kailali* district has low levels of nitrogen and organic carbon, medium levels of available potassium and phosphorus, and a neutral soil pH (MoLMAC

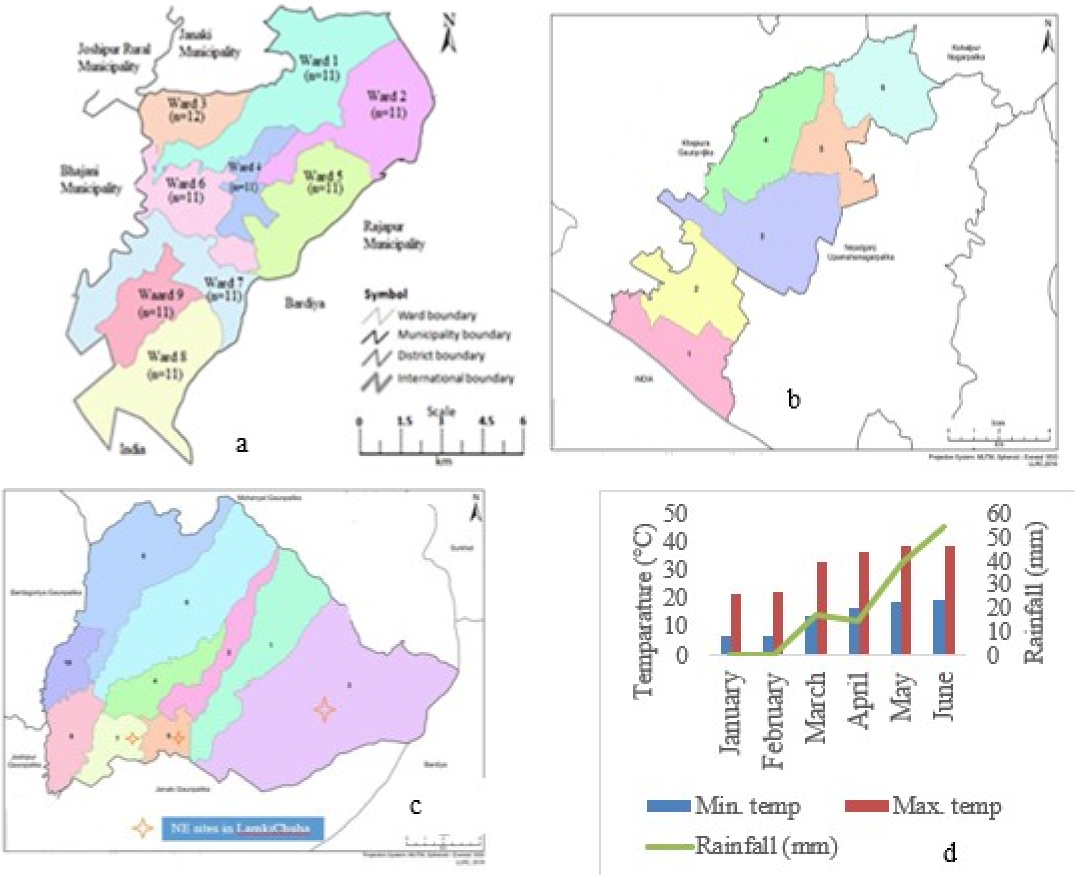

Figure 1. Map of experiment sites on NE®-Hybrid Maize and Rice Models and NOPT experimentations (a, b and c) and weather data between January and June, 2021 for spring maize and rice (d) at Tikapur municipality and Janakirural municipality (1-9 wards) and Lamkichuha municipality (3, 5 & 7 wards) areas of RJKIPC areas in Nepal.

2018). Furthermore, the weather conditions recorded throughout entire periods of spring maize and rice between January and June 2021 were conducive for the growth of these crops, as shown in figure 1.

Purposive sampling was employed to select spring rice and maize producers, specifically targeting those with innovative practices as well as individuals from underprivileged backgrounds, marginalized women, and cooperative group members. The NE®-Rice and NE®-Hybrid Maize Models were utilized, and a team consisting of faculty, students, and staff members from the School of Agriculture administered embedded questionnaires.

These questionnaires were utilized to determine the appropriate NE®-driven fertilizer dosage for 42 spring maize growers and 6 rice growers in the RJKIPC.

Field setup on NE®-Hybrid Maize and NE®-Rice Models on spring maize and rice

The NE® tool was evaluated from Feb–March 15 in 2021, across 42 farmers' fields in spring maize and 6 farmers' fields for spring rice. Open pollinated variety (OPV); Rampur Composite, and hybrid maize cultivars (*Rajkumar*), and spring rice cultivars (*Hardinath-2* and *Chaite-5*) were used as test crops in this study as shown in table 1.

The RD for hybrid maize and OPV varieties were 150:60:40 kg NPK ha^{-1} and 120:60:40 kg NPK ha^{-1} respectively and calculated for each farmer field having 50 m^2 area. The yield gaps between FFPiv and FFPfv were assessed in the studied municipal wards. Similarly, the RD for the improved rice cultivars used in the trial was set at 100:50:50 kg NPK ha^{-1}. The matrices of different NE® recommendation fertilizer

Table 1. Details of treatment used in research.

Treatments	Symbol
NE®-Hybrid Maize and NE®-Rice	NE
National recommendation dose fertilizer	RD
Fertilizer Practices of Farmers with Improved Variety	FFPiv
Fertilizer Practices of Farmers with Farmer's Variety*	FFPfv

*Control or check treatment

for farmers spring maize and rice growers along with the model predicted fertilizer doses, estimated crop yields and economics have been presented in Appendices I–III. Simultaneously, a NOPT trial for rice and spring maize was implemented in the irrigation command areas in the 18 studied municipal wards of *Tikapur, Janaki* and *Lamkichuha* (21 farmers' field with Rampur Composite) in maize, and at 3 sites of *Tiakpur-7, Janaki 4* and *Lamkichuha-7* (3 farmers' field by using *Hardinath-2*).

All treatments were designed in RCBD using diamond trial considering the farmer's field as replications. Treatments applied for spring maize and rice in the NOPT trials were: i) recommended NPK, ii) N omission (-N), iii) P omission (-P), and iv) K omission (-K). The selection of studied farmers was intentionally varied to increase heterogeneity of the studied population and numerous replications were implemented for each farmer to validate the results.

Data collection and statistical analysis

Yield attributes for rice and maize were documented at the harvest stage following their respective standard procedures (CIMMYT 2009, IRRI 2010). Grain yields for both crops were recorded from sampling areas (at least 25 m^2) using scientific crop cut survey techniques (Reddy & Reddi 2009). Grain yields and corresponding economic outcomes are compared between plots under various nutrient management strategies.

Yield gaps between the cultivars and SSNM practices in spring maize and rice were analyzed using data from NE® model and NOPT trials, focusing on the percentage change in yield across locations due to changes in crop varieties and NOPT practices. Yield and response data were analyzed using ANOVA in R-Stat software. Details of the NOPT trials are reported in table 2.

RESULTS AND DISCUSSIONS

Comparisons between the NE® Model predictions and observed data versus FFP for hybrid and OPV maize, as well as rice cultivars, in RJKIPCA

The NE® model estimated the attainable yield and profitability (NRs/ha) for hybrid maize (*Rajkumar*), OPV maize (*Rampur Composite*), and improved rice cultivars (*Hardinath-2* and *Chaite-5*) under SSNM and conventional management practices. These predictions, alongside yields from farmers' fertilizer practices with various levels of NPK recommendations. The validation of the NE®-Hybrid Maize and Rice models was established through the close alignment (within the 10–15% range) between the predicted grain yields and farmer incomes as projected by the NE® model and the actual observed values. This consistency was evident for both Spring maize and rice. Based on survey findings, rice and wheat are prioritized over spring maize across project sites. However, the satisfactory yields achieved through NE®-Hybrid Maize treatments were not fully acknowledged during field monitoring and assessments of harvest yields. The NE® Model treatment demonstrated additional benefits if farmers choose to grow maize and rice as recommended by the NE® model. Nepalese farmers' profitability is hindered by their insufficient technical knowledge in cataloging various production technologies. Therefore, adopting the NE®-Hybrid Maize and Rice models would help farmers to scientifically and technically compare and improve their

Table 2. ANOVA of spring maize and rice from NE®-Hybrid Maize and Rice models and NOPT trials.

Variables	NE®-Maize: *Lamkichuha* (Factorial RBD, V=2, SSNM=4, rep=3)	NE®-Maize: *Tikapur & Janaki* (Factorial RBD, V=2, SSNM=4, rep=9)	NOPT-Maize: *Tikapur & Janaki* (RCBD, SSNM=4, rep=9)	NE®-Rice: *Tikapur, Janaki & Lamkichuha* (Factorial RBD, V=2, SSNM=4, rep=3)
Replication	2	8	8	2
Treatment	7	7	3	7
Variety (V)	1	1	—	1
SSNM	3	3	—	3
V × SSNM	8	8	—	8
Error	14	56	24	14
Total	23	73	35	23

V = Rajkumar Hybrid and Rampur Composite

production and profitability levels.

Yields gaps assessment for spring maize based on NE-Model and NOPT trials

There was notable variation in the average grain yield of maize across nine fields in *Tikapur*, nine in *Janaki*, and three in *Lamkichuha*. The primary factor contributing to the variation in maize yield was the absence of nitrogen (N), with potassium (K) and phosphorus (P) omissions following suit (Table 3). Table 4 outlines the yield gaps observed in spring maize due to variations in varieties under the same fertilizer practices, as seen in NE trials conducted across all sites in RJKIPCA.

The findings revealed notable variations in maize yield when different varieties were utilized instead of the farmers' preferred ones. Given that maize is a cross-pollinated crop, it is recommended to renew its seeds every 2–3 years, a practice seldom followed by farmers. This resulted in diminished yields under farmers' fertilizer practices with their chosen cultivars. Moreover, the results indicated wider yield gaps when farmers opted for hybrid cultivars, particularly noticeable in *Tikapur* and *Janaki* compared to *Lamkichuha*. Nevertheless, some forward-thinking farmers at the project sites were cultivating maize hybrids, achieving significantly higher grain yields with their own fertilizer management, particularly when compared to farmers growing OPV cultivars under the NE-maize trial.

Yields gaps assessment for spring rice based on NE-Model and NOPT trials

The yield loss in spring rice due to the omission of nitrogen (N) was significantly higher than the omission of phosphorus (P) and potassium (K) across all research sites: *Tikapur-7 (Beluwa), Janaki-3 & 4 (Subarnapur & Munuwa), and Lamkichuha-7 (Hardahani)*. The highest yield losses due to N, P, and K deficiencies were noted in Janaki, followed by *Tikapur*, with the smallest reductions recorded in *Lamkichuha* (Table 5). Lower N rate at panicle initiation may decrease no. of spikelet per panicle, and consequently, decrease grain yield for a variety with small panicle size (Park *et al.* 2018). The grain yield is determined by the carbohydrate accumulated in the crop before and after heading. Before heading, the carbohydrate is accumulated in the stem and leaf sheath which is partitioned to the panicles during the grain filling period (Fageria 2007). The reduction in spring rice yields due to a change in variety was more noticeable in *Janaki* compared to *Tikapur* and *Lamkichuha*, with the *Hardinath-2* cultivar showing a greater reduction than the Chaite-5 cultivar (Table 6). The percentage yield gaps between the NE-treated plots and FFPfv plots were more distinct than those between FFPsv and FFPfv plots, likely due to the combined effects of fertilizer

Table 3. Analysis of grain yield and yield gaps on OPV cultivar (Rampur Composite) cultivated under NOPT trials.

Location/	**Yield (t ha^{-1})**				Yield gaps			Yield gaps (%)		
Treatments	NPK	(-N)	(-P)	(-K)	NPK-N	NPK-P	NPK-K	NPK-N	NPK-P	NPK-K
Tikapur (n=9)	4.51	2.87	3.52	3.82	1.63	0.98	0.70	36.22	34.46	19.73
Janaki (n=9)	5.77	2.53	4.88	3.69	3.24	0.90	2.08	56.11	35.36	42.64
Lamkichuha (n=3)	6.53	3.63	5.27	5.51	2.91	1.27	1.02	44.51	34.92	19.41
Average	5.62	3.00	4.55	4.33	2.61	1.05	1.27	45.62	35.00	27.02

Table 4. Grain yield and percentage yield gaps of spring maize under different fertilizer management strategies.

Experiment sites	Maize cultivars	FFPiv	FFPfv	% yield gaps
Tikapur (n=18)	Hybrid	7.51	5.64	1.9 (22.7)
	OPV	4.22	2.90	1.3 (27.8)
Janaki (n=18)	Hybrid	7.17	5.50	1.5 (24.5)
	OPV	5.53	4.40	1.07 (19.0)
Lamkichuha (n=6)	Hybrid	3.33	2.70	0.67 (18.8)
	OPV	3.79	2.60	1.13 (30.2)

Table 5. Evaluation of grain yield and yield gap in spring rice cultivars cultivated under NOPT trials in study area during the spring of 2021.

Locations/	Yield (t ha^{-1})				Yield gaps (t ha^{-1})			% Yield gaps		
Treatments (n=3)	NPK	N(-)	P(-)	K(-)	NPK-N	NPK-P	NPK-K	NPK-N	NPK-P	NPK-K
Tikapur	4.07	2.38	3.26	3.07	1.69	0.81	1.00	41.52	19.90	24.57
Janaki	7.50	4.02	6.04	5.02	3.48	1.46	2.48	46.40	19.47	33.07
Lamkichuha	6.26	4.38	5.74	5.40	1.88	0.52	0.86	30.03	8.31	13.74

Table 6. Grain yield and yield gaps of spring rice cultivars under NE® and farmers' practices.

Locations/ Treatments	Grain yield (t ha^{-1})				Yield gaps (t ha^{-1})		% yield gap	
Hardinath-2 (n = 3)	NE	RD	FFPiv	FFPfv	NE–FFPfv			FFPiv–FFPfv (%)
Tikapur	5.06	5.11	4.18	3.77	1.29	0.41	25.55	9.81
Janaki	6.36	5.68	4.64	3.36	3.00	1.28	47.17	27.65
Lamkichuha	5.71	5.39	4.21	3.77	1.94	0.44	34.03	10.41
Chaite-5 (n = 3)	NE	RD	FFPsv	FFPfv	NE–FFPfv			FFPsv–FFPfv (%)
Tikapur	4.69	4.00	4.28	4.17	0.52	0.11	11.01	2.52
Janaki	5.71	5.15	5.11	5.00	0.71	0.11	12.39	2.11
Lamkichuha	4.26	3.55	3.19	2.29	1.97	0.90	46.20	28.20

and variety in the NE® treated plots. The higher yields observed in NE-treated plots for spring rice indicate that the NE®-Rice Model is effective for achieving higher yields and can be recommended for managing fertilizer in the RJKIP command areas. NE tool provided adequate guidance to apply the required rate of fertilizer that matched the crop requirement and soil nutrient supply of each farmer fields (Amgain *et al.* 2021).

Statistical examination of yield characteristics and yield of spring maize in RJKIPCAs utilizing ANOVA

Although not all data sets are shown, important yield parameters like biological yield, cob numbers, cob length, kernels per row, kernels per ear, and harvest index were significantly higher for the hybrid maize variety in *Tikapur* compared to the OPV variety. However, cob and nubbin weight had statistically similar results for both varieties (Table 7). Out of four SSNM practices tested on farmers' fields, the plot with the recommended doses of fertilizer by the Nutrient Expert model exhibited significantly higher biological yield, cobs numbers, and kernels per row. In contrast, yield attributes such as cob length, nubbin, and cob weight had statistically similar results across all tested models. Of the four tested models, FFPfv reported the lowest yield attributes.

In *Janaki*, tested varieties showed no significant differences in kernel rows per cob, nubbin, and cob weight. However, the OPV variety had a significantly higher harvest index (40.56%) compared to the hybrid variety (33.99%) (Table 8). Among the four SSNM models tested, the Nutrient Expert Hybrid Maize model's fertilizer dose recommendations resulted in a higher number of cobs per hectare (48,000) than other models. *Janaki* sites showed no significant differences in nubbin yield, ear length, ear weight, and kernel rows per cob among the tested models (Tables 7 and 8). Among the four SSNM models tested (NE-Hybrid Maize Model, RD, FFPiv, and FFPfv), the NE model recommended fertilizer dose resulted in a significantly higher number of cobs per hectare (40,066.67) compared to all other treatments in farmers' fields. Nubbin and ear weight and ear length were statistically similar across all tested models. Farmers' fertilizer practice with their own variety had lower yield and most yield attributes (Table 8). In all experimental sites in *Kailali* district, two maize cultivars were tested under four different SSNM treatments in farmers' fields. The hybrid had significantly higher grain yield (7.94 t ha^{-1}) than the OPV cultivar (4.01 t ha^{-1}) at *Tikapur*. Similarly, the kernel yield was significantly higher (7.19 t ha^{-1}) in the plot treated with the fertilizer dose suggested by the NE®-Hybrid Maize model among the SSNM treatments tested in farmers' fields in *Tikapur* (Table 8). In the *Janaki* study, the hybrid cultivar exhibited significantly greater grain yield (7.14 t ha^{-1}) than the OPV cultivar. Of the four SSNM fertilizer treatments tested, the NE®-Hybrid Maize model's recommended dose yielded the highest kernel (7.38 t ha^{-1}) outputs in *Janaki*. At *Lamkichuha*, there was no notable difference in grain yield between OPV and hybrid cultivars. However, OPV cultivar cob yields were significantly higher (6.51 t ha^{-1}) than the hybrid (5.06 t ha^{-1}). This indicates that rural farmers may be proficiently applying scientific cultivation practices to local cultivars, which might also show greater resilience to climate change (Timsina*et al.* 2010).

Out of four SSNM practices (NE®-Hybrid Maize model, RD, FFPiv, and FFPfv), the NE®-Hybrid Maize model's recommended dose led to the highest grain yield (5.07 t ha^{-1}) in farmers' fields (Table 8). The Nutrient Expert (NE) model tool has now been selected as the best ICT solution for improving rural livelihood of all Indian States and especially of Bihar, UP and West Bengal (Sapkota *et al.* 2021). Bhatta and Aggarwal (2015) also reported that the NE tool is also one of the important flagship interventions for the Climate Smart Villages under the CGIAR research program on Climate Change, Agriculture and Food Security (CCAFS) in India. Figure 2 provides a summary of the yield results for spring maize cultivars grown using NOPT in the experiment areas of *Kailali* district.

The results show maize grain yield were considerably higher on plots treated with NPK

Table 7. Yield component of maize cultivars using NE-Hybrid Maize Model treatments.

Treatments	Tikapur (n=18)		Janaki (n=18)		Lamkichuha (n=6)	
	Cob no. ha^{-1}	Nubbin wt. (t ha^{-1})	Cob no. ha^{-1}	Nubbin wt.	Cobs ha^{-1}	Nubbin wt.
Cultivars						
OPV	44461.72^{b}	1.852^{a}	41388.89^{b}	1.80	43200.00^{a}	2.10^{a}
Hybrid	49029.61^{a}	2.188^{a}	42033.33^{a}	2.05	28566.67^{b}	1.26^{a}
LSD (0.05)	0.780	0.780	0.78	0.78	1.44	1.44
CV (%)	0.0003	8.84	0.003	8.56	0.004	9.22
SSNM practices						
NE	51207.39^{a}	2.29^{a}	48000.00^{a}	2.25^{a}	40066.67^{a}	1.54^{a}
RD	50282.11^{b}	2.14^{a}	41044.44^{b}	1.85^{a}	38000.00^{b}	1.79^{a}
FFPiv	43513.56^{c}	1.81^{a}	39044.44^{c}	1.79^{a}	34400.00^{c}	1.65^{a}
FFPfv	41979.61^{d}	1.82^{a}	38755.56^{d}	1.81^{a}	31066.67^{d}	1.74^{a}
LSD (0.05)	1.104	1.10	1.103	1.10	2.04	2.04
CV (%)	0.003	8.84	0.003	8.56	0.004	9.22

Table 8. Grain yield (t ha^{-1}) and harvest index (HI) (%) of maize cultivars and SSNM practices.

Treatments	Tikapur (n = 18)		Janaki (n = 18)		Lamkichuha (n = 6)	
	Grain yield	HI (%)	Grain yield	HI (%)	Grain yield	HI (%)
Cultivars						
OPV	4.01^{b}	31.08^{b}	5.57^{b}	40.56^{a}	3.97^{a}	24.92^{a}
Hybrid	7.94^{a}	43.32^{a}	7.14^{a}	33.99^{b}	3.79^{a}	25.88^{a}
LSD (0.05)	0.78	0.78	0.79	0.77	1.43	1.43
CV (%)	17.62	4.43	15.99	4.42	12.58	6.50
SSNM practices						
NE	7.19^{a}	36.56^{b}	7.38^{a}	35.96^{c}	5.07^{a}	27.92^{a}
RD	6.62^{ab}	39.05^{a}	6.70^{ab}	37.81^{b}	4.25^{ab}	26.64a
FFPiv	5.8^{b}	39.02^{a}	6.23^{b}	39.81^{a}	3.55^{ab}	26.21^{a}
FFPfv	4.28^{c}	34.22^{c}	5.11^{c}	35.52^{c}	2.65^{b}	20.82^{b}
LSD (0.05)	1.10	1.10	1.10	1.10	2.04	2.04
CV (%)	17.63	4.44	15.98	4.43	12.59	6.51

(4.22 t ha^{-1}) compared to plots where N and P were omitted, although the yields from these two treatments were statistically similar in *Tikapur*. The lowest observed grain yield was on plots where nitrogen was omitted (-N) (2.88 t ha^{-1}). Results in the Janaki Rural Municipality, also showed significantly higher spring maize grain yields on NPK plots (5.76 t ha^{-1}) than plots with omissions of N and P. However, NPK plots were statistically similar to plots where potassium was omitted (4.88 t ha^{-1}).

Application of optimum fertilizer at early stage under NPK-treated plots resulted in proper germination, crop vigor, and optimal plant population, leading to higher numbers of cobs per hectare, kernels per kernel row, and 1000-grain weight, ultimately resulting in higher grain yield (Timsina *et al.* 2021, Marahatta 2021).

The inconsistent fertility status of the soil in the RJKIP sites reveals a significant deficiency in nitrogen (N), leading to low cereal crop yields in the eastern Terai (Timsina *et al.* 2022). The omission of nitrogen (-N) resulted in significantly lower values for various yield attributes compared to phosphorus (P) and potassium (K) omissions. Potassium plays a crucial role in maintaining the catalytic function of nitrogen and phosphorus; therefore, plots where potassium was omitted showed increased susceptibility to major pests and diseases,

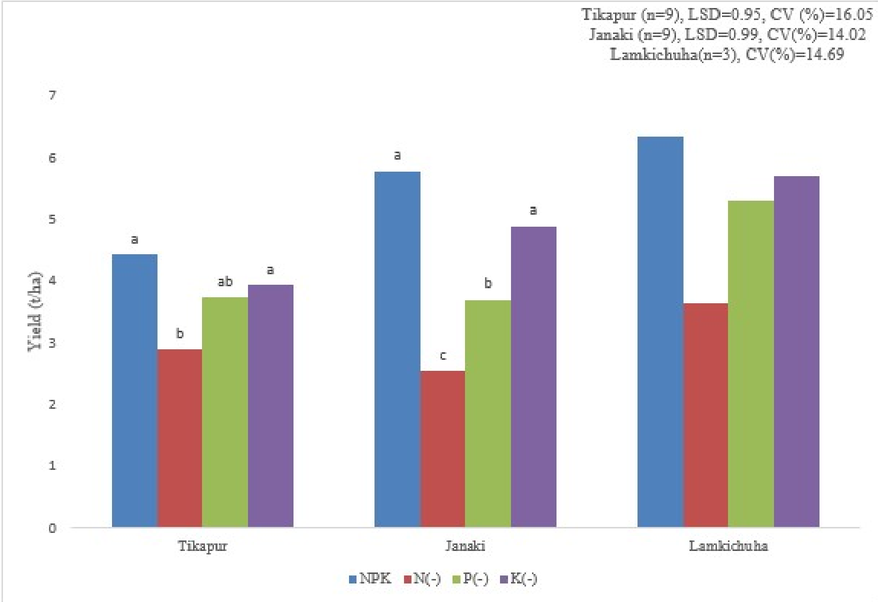

Figure 2. Grain yield of maize cultivars subjected to NOTP trials in the RJKIP Tikapur.

leading to reduced yields and yield attributes (Timsina *et al.* 2010). The soil's inconsistent fertility in RJKIP sites has highlighted the predominance of nitrogen deficiency, which contributes to diminished cereal crop yields. Additionally, the soil inventory map of *Kailali* district, released by the Soil Science Directorate of the Ministry of Agriculture, indicates very low levels of nitrogen and soil organic carbon (SOC), along with medium levels of phosphorus and potassium in the surface soil of Kailali (MoLMAC 2018).

Yield and Yield Components of Spring Rice

A preliminary examination of the on-farm field trial data conducted across three sites (*Tikapur, Janaki*, and *Lamkichuha*) in *Kailali* district, focusing on the yield and yield responses of spring rice using the NE-Rice Model for two spring rice cultivars (*Hardinath-2* and *Chaite-5*), revealed that the grain yield of the rice cultivar *Hardinath-2* (4.77 t ha^{-1}) was marginally higher than that of *Chaite-5* (4.28 t ha^{-1}), although this difference was not statistically significant. Similarly, the biological yield of the *Hardinath-2* cultivar was significantly greater than that of the *Chaite-5* cultivar (Table 9).

Yield parameters such as total tillers per square meter and harvest index did not show significant differences due to the influence of different cultivars used in the trial.

However, among the four SSNM fertilizer doses tested across two cultivars at three locations, the NE-Rice model treatment demonstrated a notable increase in yield and yield parameters of spring rice. The grain yield of the plot treated with fertilizers recommended by the NE model was significantly higher (5.29 t ha^{-1}) than that of the other three SSNM models tested. However, biological yield of spring rice did not show significant differences across SSNM treatments. Previous researchers have also highlighted the significant superiority of NE treatments in *Lamahi Dang* and *Bhaktapur, Lamjung, Kavrepalanchowk*, and far-eastern Nepal, respectively (Sapkota *et al.* 2021, Sarkar *et al.* 2022).

The FFPfv treatment appeared relatively inferior compared to the other treatments, emphasizing the importance of increasing the seed replacement rate to enhance spring rice yield at the farmer's field level.

Table 8 presents the yield attributing characteristics, yield, and their responses, including harvest index and tiller response in terms of tiller panicle conversion index of the cultivar *Hardinath-2*, cultivated under NOPT trials at RJKIP. The average grain yield recorded

Table 9. Yield and yield responses of spring rice cultivars treated with NE in RJKIP.

Treatment	Grain yield (t ha^{-1})	Total tillers/m^2	Biological yield (t ha^{-1})	Harvest index (%)
Cultivar				
Hardinath-2	4.77^a	350.95^a	15.84^a	30.69^a
Chaite-5	4.28^a	358.95^a	12.74^b	33.60^a
LSD (0.05)	0.52	18.68	1.64	3.80
SSNM fertilizer practices				
NE	5.29^a	402.16^a	15.50^a	34.79^a
RD	4.81^{ab}	367.66^b	13.98^a	35.11^a
FFPiv	4.20^{bc}	340.50^c	14.06^a	30.43^{ab}
FFPfv	3.79^c	309.41^d	13.62^a	28.24^b
LSD (0.05)	0.74	26.43	2.32	5.38
CV (%)	13.27	6.01	13.14	13.51

Table 10.Yield and yield components traits of spring rice cultivars under NOPT treatments in the RJKIP areas

Treatments (n = 12)	Grain yield (t ha^{-1})				Biological yield (t ha^{-1})				HI (%)			
	Tkp	Janaki	Lamki	Mean	Tkp	Janaki	Lamki	Mean	Tkp	Janaki	Lamki	Mean
NPK	4.07	7.50	6.26	5.94	14.05	16.80	15.43	15.43	28.97	44.63	40.58	38.06
N (-)	2.38	4.02	4.38	3.59	8.69	8.98	9.51	9.10	27.39	44.77	46.06	39.41
P (-)	3.26	6.04	5.74	5.01	10.42	11.94	12.18	11.51	31.30	50.60	47.13	43.01
K (-)	3.07	5.02	5.40	4.50	9.98	10.85	11.27	10.70	30.75	46.28	47.91	41.65
Mean	3.20	5.65	5.45	4.76	10.78	13.20	12.10	11.68	29.60	46.57	45.42	40.53

was 4.76 t ha^{-1}, with the highest grain yield observed in the NPK treatment.

Conversely, the omission of nitrogen significantly reduced rice grain yield, followed by potassium omission, with the least impact observed with phosphorus omission, as indicated in Table 10. Comparable results for biological yield and harvest index were noted, as documented by Sarkar *et al.* (2022).

CONCLUSION

The NE®-Hybrid Maize and NE®-Rice models have accurately forecasted spring maize and rice yields and have projected positive economic outcomes, ensuring a consistent increase in attainable yield compared to traditional farmer fertilizer practices. Therefore, it is recommended to adopt the NE®-Hybrid Maize and NE®-Rice models as reliable decision-support tools to enhance soil fertility management and crop production in the RJKIP command area of *Tikapur, Kailali*. The study focused solely on spring maize and a limited area of spring rice within the project command area of RJKIP, involving a few farmers from *Tikapur, Janaki*, and select farmers from *Lamkichuha*. Given current circumstances, it is anticipated that the project's activities will have spill-over effects to neighboring agro-ecological areas of *Tikapur*. The NE® model should be validated to ensure it provides cost-effective fertilizer recommendations beyond the scope of this study, covering Nepal's major crop production regions including *Kailali, Kanchanpur, Banke*, and *Bardiya*. For more robust and dependable conclusions, it is recommended to continue multi-location on-station and on-farm trials for at least 2–3 years with an increasing number of participating farmers. By conducting routine soil analysis on selected soil samples, the validity of the NE® model and NOPT fertilizer trials can be further verified, facilitating their broader application across larger areas.

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