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Rice Subsector Development and Farmer Efficiency in Nepal: Implications for Further Transformation and Food Security

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With economic development agricultural systems in the Global South transform from subsistence farming to higher productivity with market integration and increase in rural income and food security. In Nepal, agriculture continues to provide livelihoods for two-thirds of the predominantly rural population, largely at a subsistence-level. Rice is the staple food and covers the largest land area but yields are relatively low, with an annual import bill of USD 300 Million. The study uses data from 310 households from two distinct rice producing areas to assess farmers' rice production systems. It analyses farmers' rice production efficiency using a stochastic frontier production function to suggest how to advance the transformation of Nepal's rice sector. Our study finds that while agriculture related services such as access to inputs, information, markets, irrigation, and finance have generally improved, paddy farmers are only able to achieve 76% of potential output. Small/marginal farms were relatively less efficient than medium and large farms. Women farmers faced unequal access to technologies and have lower productivity than men. Unavailability of labor and capital, land fragmentation, and the lack of consistent access to seed and fertilizers contribute to reduced efficiency. Public and private sector investments are needed to enhance the timely and adequate access to quality seeds, fertilizers, processing facilities, and equipment services. Adopting a market systems approach through cooperative farming, targeted delivery of extension services, and linkages with rice millers can promote inclusive growth and improve rice food security in Nepal.

Keywords: rice, efficiency, agriculture transformation, market system, inclusive growth

INTRODUCTION

Agricultural transformation is critical to develop economies and achieve the Sustainable Development Goal (SDG) 2 to "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture" (UN, 2015). Agricultural transformation opportunities and needs vary across the Global South. Here we focus on the case of Nepal—a landlocked country in South Asia, with a challenging mountainous terrain and market infrastructure where agriculture continues to provide livelihoods for two-thirds of the population, largely at a subsistence-level (ADB, 2019; IBN, 2019). Nepal's agricultural sector is variously challenged by declining per capita arable land, limited access and use of new technologies, and inadequate input supply chains that often limit timely availability of critical inputs like fertilizer, irrigation, and machinery (Timsina and Connor, 2001; Paudel et al., 2019; Tripathi et al., 2019; MoALD, 2020).

Nepal's food security depends on the production of staple cereals with rice being the main cereal. Rice is grown on 1.49 million ha in Nepal with an average productivity of 3.5 t/ha and total annual production of 5.6 million tons in 2018 (MoALD, 2019). The total annual demand of milled rice in Nepal is estimated at 4.08 million tons (6.56 million tons of paddy) against a production of 3.25 million tons milled rice (5.2 million tons paddy) in 2017. Nepal imported 0.75 million tons of milled rice in 2019 (TEPC, 2020). Gairhe et al. (2021) reported rice import quantity and value to be increasing at the rate of 24.48 and 38.11 percent per annum, respectively, while production growth was <2% per annum. The Government of Nepal has prioritized increasing domestic rice production to reduce the import bill of USD $300 million each year.

Rice is cultivated in three distinct agro-ecological regions viz., *Terai* (the Gangetic plains), mid hill and high hill with a share of 68, 28, and 4%, respectively (Gauchan et al., 2014; MoALD, 2020). The per capita consumption of rice in Nepal is 138 kg, and it contributes 16% to the agriculture GDP and 52% to the total cereal consumption in the country (Yadav and Chaudhary, 2017). Nepal ranks 17th in rice production and 64th in rice productivity in the world. Till date, the Nepal Agriculture Research Council (NARC) has developed 82 rice varieties and an additional 48 hybrid rice varieties have been registered with the Government of Nepal. Nevertheless, the productivity of the rice sub-sector in Nepal (3.5 t ha^{-1}) lags in comparison to other neighboring countries Bangladesh (4.4 t ha^{-1}) and China (6.7 t ha^{-1}) albeit at par with India (3.7 t ha^{-1}), and Pakistan (3.5 t ha^{-1}). Between 1960 and 2017, the annual growth rate of rice yield in Nepal was 1.14% which is substantively less than the neighboring countries such as India (2.5%), Bangladesh (3%) and China (4.2%), and world average (4.5%) (FAOSTAT, 2019). There is also high yield gap (50%) among farmers (NRRP, 2019).

Over the last decade, increased access to improved rice varieties (including hybrids) and other technological interventions have helped farmers to increase rice production. Still land productivity (yield) is relatively low in Nepal compared to neighboring countries like Bangladesh (MoAD, 2014), which also successfully progressed to self-sufficiency. Despite several plans and programs to boost rice sector growth, realized growth has not resulted in the policy goal of achieving national self-sufficiency in rice production. Horizontal expansion by bringing more area under rice cultivation is untenable given the limited arable terrain which is already intensively used for food production and settlements.

Nepal potentially can become self-sufficient in rice, but this is possible only through rapid productivity increases and closing yield gaps. Such radical changes will require accelerating the agricultural transformation process. Despite agricultural practices in Nepal being largely traditional, agricultural systems are changing rapidly with mechanization, use of improved seeds and inputs becoming increasingly common (Thapa et al., 2020a), although they are rarely applied at the agronomic optimum.

AGRICULTURE TRANSFORMATION AND RICE SUBSECTOR

The focus of this research is on rice which is the major staple crop of Nepal. Agricultural transformation (AT) implies farmers rapidly change their mode of production, typically embracing intensified use of critical inputs (e.g., new varieties, balanced fertilizer, mechanization, and irrigation) enabled by improved access to finance, markets and transport networks (Schultz, 1964). Understanding the status and changes in rice production and commercialization can provide a better understanding of the transformation of cereal systems and to a larger extent on AT in Nepal. Over time with the broadening of the AT concept, it can also mean increased productivity and commercialization in agriculture alongside economic diversification and growth (Vos, 2018; Achim and Fan, 2019).

The AT drivers and enabling factors are multidimensional, interrelated, and change over time. The first and foremost element is the government institutional framework and policy programs or "transformation readiness" (Timmer, 1988). The Government of Nepal has launched its Agriculture Development Strategy (ADS 2015-35) that aims to promote linkages between agriculture and other sectors in the economy for the growth of an overall robust economy, a more balanced rural economy, and employment generation. AT is a complex process and not easily implemented or promoted, even if agriculture is prioritized by the governments in the national development plan. Part of the problem is because agricultural programs are broadly focused with multiple goals (Boettiger et al., 2017). A conducive enabling environment must be provided by the government that increases access to modern technologies, attracts private sector investments, improves connectivity between rural and urban centers, and expands road and communication networks in addition to systems that overcome barriers to equal access by smallholder and marginalized farmers. From the 12th Plan (2010/11–2012/13) the Government of Nepal (GoN) has provided high priority to paddy production, focusing on agricultural inputs subsidies (CDD and ASoN, 2017) and investment in irrigation infrastructure (Tripathi et al., 2019). From the 13th Plan (2013–2017), subsidies were provided for machinery and equipment to overcome labor shortages and crop insurance schemes were introduced. In the 13th plan, the GoN has also provided increased attention to rice by launching Fine and Aromatic Rice Promotion Programme and Mega Rice Promotion Programme (CDD and ASoN, 2017). The Prime Minister Agriculture Modernization Project (PMAMP) was developed by setting up a rice super zone, with post-harvest, laboratories, custom hiring facilities (CDD and ASoN, 2017).

In Nepal, there is limited information available on farmers' rice production systems with the aim to highlight agricultural transformation. Nepal has seen rapid changes in agricultural services, infrastructure, access to finances, and communication off late in the Terai and hills, but many of these changes are yet to be analyzed or their implications understood. Considering the Government of Nepal's quest for food and nutritional security there is a need for deeper insights into the rice production systems and farmers efficiency. Several AT studies are at the macro level or aggregate studies carried at the country or regional or provincial levels (Dawe, 2015; Ecker, 2018). This paper provides such insights for two contrasting rice producing locales in the mid-hills and Terai by using household data to describe farmers' rice production systems and analyses rice production efficiency to understand how to further the transformation of Nepal's rice sector. We use these empirical findings to explore the challenges toward the further transformation of Nepal's rice sector. The remainder of this paper is divided into three sections. Section 2 on materials and methods describes the research methodology and data collection. Section 3 presents the results on rice production systems and farmers efficiency. Sections 4 discusses the results and provides conclusions to further transform the rice sector.

MATERIALS AND METHODS

The study uses Nepal's Nuwakot and Chitwan districts as two study locales. Paddy cultivation is a major agricultural activity in each district, but Nuwakot is located in the mid-hills and Chitwan in the Terai. The two sites also differ in road access, commercial output and input markets, wider transport network and services, and availability of private and public sector institutions that provide goods and services including financial to farmers. Chitwan is centrally located along Nepal's east-west highway in the Terai and has large market centers and connectivity to Indian markets. Nuwakot is in the central mid-hills, with a relatively limited road network and access to markets, albeit its in relative proximity from Kathmandu in the central valley.

In Chitwan, six rural municipalities—Bharatpur, Kalika, Madi, Khairhani, Rapti and Ratnanagar were selected for study in consultation with the faculty members of the Agriculture and Forest University at Rampur, Chitwan. In Nuwakot, four rural municipalities (Thansing, Dhikure, Dobate, and Kalimati) were selected in consultation with the Krishi Gyan Kendra (Agriculture Knowledge Center) of Bagmati Province. Five focus group discussions with farmers and two key informant interviews with agrodealers were organized to obtain information on general rice production practices and marketing to design the questionnaire. Focus group discussions and interviews were also to used understand the macro aspect of the agricultural transformation process related to the availability of modern inputs, price, government subsidy etc. The information was also used to complement discussions of the results. In both the study areas, most farmers were already using modern inputs such as improved seeds, chemicals, and agricultural equipment.

A questionnaire was drafted and tested with households in the study areas which helped to clarify and rephrase the several questions. A one-day orientation program was organized for the enumerators which helped them to understand the questions. After adjusting the questionnaire to the local situations, face to face interviews was used to collect information on farmers' rice production practices, inputs used and marketing using a structured questionnaire through the Open Data Kit (ODK). A purposive random sampling approach was adopted to survey 310 households (210 in Chitwan and 100 in Nuwakot) in 2019, with 197 households with complete data retained for the econometric analysis. Purposive sampling is a cost-effective and time-effective sampling method that allows a researcher to identify respondents whose availability and attitude are compatible with the study. The respondents were the head of the household. During the interviews it is common among the farming community to have other people sit around the respondent and share their opinions. The final answer provided by the respondent was only noted.

The size of holding or area cultivated is small in Nepal with many farmers cultivating or owning <0.5 ha of land. For analytical purposes the farmers were divided into three structural farm size classes viz., marginal and small <0.5 ha; medium 0.51–0.7 ha; large >0.71 ha. Farmers are often grouped into five groups based on the size of their land holdings or area cultivated if the sample size if large, but when sample size is small the groups are reduced as done in the present study. Production efficiency is one of the metrices for agricultural development. Technical inefficiency implies that for a given bundle of technology, input prices and other socioeconomic variables, farmers are unable to maximize outputs. The stochastic frontier enables to estimate this deviation across farms and also analyses variables that are influencing this deviation. Technical efficiency is estimated using a stochastic frontier production function following Aigner et al. (1977) by using STATA 15. It became popular in the econometric literature after the pioneering studies by Aigner et al. (1977) and later by Coelli and Battese (1996). Many studies measuring technical inefficiency have since followed (Huynh-Truong, 2009; Piya et al., 2012; Khanal and Maharjan, 2013; Mango et al., 2015; Boubacar et al., 2016). To allow for the measurement of the technical inefficiency the stochastic frontier production function (Equation 1) consists of two error components: a Gaussian error term and a truncated error term. While the Gaussian error component (V) is assumed to be distributed normally with a constant variance, the second error component (U) is assumed to have a non-negative truncated distribution implying that technically inefficient points lie below the production frontier (Kumbhakar et al., 2015; Mango et al., 2015).

$$\mathrm{Y^*}_\mathrm{i} = f(Xi, \beta k)\exp(\mathrm{V_i} - \mathrm{U_i}) \tag{1}$$

Where,

Y_i is the observed output of the ith paddy producer/farm;
f is the production frontier technology assumed to characterize paddy production;
Xi is the vector of the variable inputs used by the farms.
β's is a vector of parameters to be estimated.

V_i represents the symmetrically distributed random error component beyond the farmer's control and is distributed normally with a mean of zero and a constant variance ($sigma_v^2$); and

U_i are one sided positive stochastic error terms representing deviations from the frontier responsible for inefficiency and values range between 0 and 1. This term follows the half normal distribution with a zero mean and variance ($sigma_v^2$).

Technical Efficiency in paddy production (TE) is the ratio between observed paddy output (Y) and maximum possible paddy production (Y*) and the difference in (Y*-Y) is the result of inefficiency U_i.

$$TE_i = \exp - (Ui) = Yi/Y^*{}_i \text{ so that } 0 \leq TE_i \leq 1 \quad (2)$$

$$\ln Y_i = b_o + b_1{}^*\ln(\text{seed cost}) + b_2{}^*\ln(\text{chemical/fertilizer cost}) + b_3{}^*\ln(\text{capital service cost}) + b4^*\ln(\text{labor cost}) + e_i(V_i - U_i) \quad (3)$$

Technical inefficiency is assumed to be determined by the variables listed in Equation 4 and described below.

$$Ln(U_i) = d_0 + d_1{}^*REGION + d_2{}^*GENDER + d_3{}^*HHEDU + d_4{}^*HHSIZE + d_5{}^*YRSFARMP + d_6{}^*MKTIME + d_7{}^*FRAGMENT + d_8BNKAGE + d_9{}^*RICEHA + w_i\ (0 < TE_i <= 1) \quad (4)$$

U_i is technical inefficiency, d_i are parameters associated with the socio-economic characteristics of the farm households and w_i is a random error term. The stochastic production frontier (Equation 1) and the technical inefficiency equation (4) are jointly estimated by the maximum likelihood method, assuming a half normal distribution of random error term w_i.

The dependent variable is the total paddy output produced by the farm households expressed in natural log form (Equation 3). Cost information was collected over nine cultivation activities and aggregated into seed, chemical fertilizer, capital services and labor[1]. Labor is the primary input and cost—with reported labor scarcity and rising wages. Households use different forms of capital such as pump sets and sprayers and most hire tractors and power tiller services. Expenses on fertilizer and other chemicals such as insecticides and pesticides are the third cost component. Majority of the farmers purchase either hybrid or improved seeds and the use of older cultivars is negligible.

Variables commonly assumed to affect technical inefficiency in farming (Equation 4) relate to the socio-economic characteristics of the household head (such as experience, age, gender), linkages to extension services and farm structure (such as land fragmentation, ownership of livestock) (Coelli and Battese, 1996; Mango et al., 2015; Tleubayev et al., 2017; Rana and Bapari, 2018). In this study nine variables have been considered (**Table 1**).

The functioning of the rice market system and their underlying factors was analyzed qualitatively based on personal observation, results of focus group discussions; interviews with stakeholders, agro-dealers, and cross verification. Household data and information collected from group discussion with farmers and key informant interviews with market actors and facilitators was analyzed based on descriptive statistics. Simple linear regression was conducted to assess the relationship between farm size and yield. The F test was used to compare results across groups.

[1]The nine different categories were: organic fertilizer, chemical fertilizer, herbicides and pesticides, sowing and planting, intercultural operations, harvesting and threshing, irrigation and water management and transport and storing. Labor was the most important cost throughout the categories.

RESULTS

Rice Production Systems

Farm Household Characteristics

The socioeconomic characteristics of the households are presented in **Table 2**. Majority of the households were male headed in both the study areas. Household heads in Chitwan had more years of schooling than those in Nuwakot, a difference that persisted at the gender level. Farming experience also was found to be higher among males relative to female heads within the two study areas. The size of households in terms of adult members was higher in Chitwan.

Seed Use, Area Planted, and Yield

In the study sites, most of the households cultivate rice on their own lands—renting land is uncommon. On average each household cultivates 0.6 ha of rice annually (**Table 3**). Virtually all (96%) the households cultivate modern rice varieties (open-pollinated varieties [OPVs] or hybrids), with only a few using local varieties. Hybrid rice cultivation is markedly more common in Nuwakot (**Table 3**). In both the sites the farmer-reported average paddy yield was higher than the national average of 3.5 t/ha. Average yield of hybrid rice was similar in the two areas, whereas hybrid rice had higher yields than OPVs ($F = 3.2$; $P = 0.01$). The OPVs had markedly lower yields in Nuwakot (albeit from a limited number of observations), both compared to hybrids in Nuwakot ($F = 11.79$; $P = 0.01$) and to OPVs in Chitwan.

The yield of hybrids and OPVs differed across the three farm size groups ($F = 5.79$; $P = 0.01$) (**Table 4**). A simple linear regression between yield and farm size reflects a negative relationship between farm size and yield [Yield (kg/ha) = 5561.76 ($t = 21.05$)−894.13 paddy area ($t = 2.75$), $R^2 = 0.26$]. Chitwan had a uniform level of development in terms of road network and access to inputs and output markets and technology. Whereas, in the hilly terrain of Nuwakot this development is relatively more confined to the roadside areas and not uniform and may explain for the observed variation in paddy yields across farm size.

Yields were higher in irrigated lands than in partially irrigated or rain fed land in both the study areas as well as across the study areas ($F = 4.08$; $P = 0.01$). The yields of the crop by seed variety and irrigation status are provided in **Table 5**.

Fertilizers and Irrigation

In Nuwakot, 70% of household perceived that timely availability of fertilizer had improved now compared to 10 years ago, while about 7% indicated that situation had remained same and 23% indicated it had become worse. The results are similar in the case of Chitwan (61% improved; 33% worse and 6% same).

TABLE 1 | Variables used in the study.

Variable name	Variable description	Expected sign of coefficient
Inefficiency effects		
REGION DUMMY (0 = Nuwakot, 1 = Chitwan)	Captures the differences between the two study areas. Chitwan has many positive features relative to Nuwakot that are conducive to make paddy production relatively more efficient	-
GENDER DUMMY- household head (female = 0, male = 1)	Assumed to capture reflect inefficiency arising from farmer's gender in rice production.	Ambigious
HHEDU (Years of schooling completed by household head)	Education as an input in production is expected to reduce inefficiency and the expected sign of this variable is negative.	-
HHSIZE (household size members > 18 years)	This variable is expected to reduce inefficiency if the educated members also worked on the farm. While some members spend some time on the farm despite full time off farm work, many family members although live in the farm, prefer to work outside the farm or work abroad. Hence the sign is ambigious.	Ambigious
YRSFARMP (years of experience in paddy farming)	Years of cultivating improved paddy (YRSFARMP) is used to capture farmers experience in improved paddy production. Lack of experience is expected to enhance inefficiency. The expected sign of this variable is negative	-
MKTIME (time to reach market in minutes)	Improved access to markets in terms of reduced travel time is expected to have positive impact—reduce inefficiency—on paddy yields for variety of reasons including reduced inputs costs, increased farm gate prices of outputs, reduced transaction and transport costs. As a result, the expected sign of this variable is negative.	-
FRAGMENT (land fragmentation)	Household land holding is often spread across several parcels, more in hilly Nuwakot than in the plain land of Chitwan. Cultivating paddy in more than one piece of land that is not contiguous adds to cost and hence this variable is expected to increase inefficiency and its sign is expected to be positive.	+
BNKAGE (years having bank account)	The number of years since a household holds an account in a commercial bank is used to proxy commercialization of farming activities. Thus, farmers whose bank accounts are new are likely to know less about commercial farming such as input and output prices, availability of loans, market centers, etc., and are likely to be more inefficient than farmers who have had longer association with banks. The coefficient of this variable is likely to be negative.	-
RICEHA (rice cultivated area, Ha)	The rice area owned (farmed) by household is assumed to influence production efficiency in a positive way. As the area farmed decreases households are unable to benefit from bulk purchases and exploit the economies of scale and this adds to inefficiency. The coefficient of this variable is expected to be negative.	-

TABLE 2 | Socioeconomic information of households in study areas, Nepal.

	Nuwakot (mid-hills)	Chitwan (Terai)	*F* (sig)
Male headed household	79%	80%	
Mean age household (hh) head	51.7 (±11.5)	50.6 (±10.1)	0.55 (0.46)
Male—female hh heads	53.3–45.1	52.5–43.3	
Mean years in farming	28.5 (±12.4)	25.4 (±11.5)	4.35 (0.03)
Male—female hh heads	30.1–22.5	27.4–17.5	
Years of schooling hh head	6.3 (±5.07)	7.9 (±4.72)	7.18 (0.00)
Male—female hh heads	6.5–5.5	8.3–6.3	
Household size-adults above 18 years only	3.86	4.34	6.49 (0.01)

Source: Household survey, 2019. Standard deviations are provided in brackets.

TABLE 3 | Paddy yield and area in study areas, Nepal (kg paddy/ha, farmer reported).

	Nuwakot (mid-hills)	Chitwan (terai)
Paddy area (ha)	0.65 (±0.43)	0.59 (±0.63)
Hybrid seed use	87%	26%
Paddy yield (mt/ha)	4.74 (±2.04)	4.65 (±2.22)
Hybrid	4.99 (±2.00, 87)	5.02 (±2.09, 51)
OPV	2.87 (±1.35, 12)	4.57 (±2.24, 133)

Source: Household survey, 2019.
In-between brackets: (std deviation, n).

In the case of adequacy of fertilizers 19% household perceived situation to have become worse off in Nuwakot and in Chitwan this percentage was 26%.

During focus group discussions with farmers, it was found that farmers use less amount of nitrogen and potassium but higher amount of phosphorus across the study districts. These rates varied with the nationally recommended rates of 100 kg/ha nitrogen, 30 kg/ha phosphorus, and 30 kg/ha potash. In addition, farmers applied FYM 10–15t/ha both in Nuwakot and Chitwan. Cooperatives were the main source of chemical fertilizers and these organizations are located at 10–15 min walking distance in Chitwan and 30–60 min walking distance in Nuwakot.

TABLE 4 | Rice yield variation by seed type, farm size and study areas, Nepal (kg/ha, farmer reported).

		Nuwakot (mid-hills)	Chitwan (terai)
Hybrid	Marginal & Small	5,311 (1,949, 55)	4,993 (2,246, 34)
	Medium	4,893 (2,528, 13)	4,119 (1,498, 11)
	Large	4,149 (1,557, 19)	6,807 (2,036, 6)
OPV	Marginal & Small	3,539 (1,369, 6)	4,219 (2,246, 67)
	Medium	2,390 (1,057, 2)	4,957 (2,191, 32)
	Large	2,649 (1,595, 5)	4,699 (2,344, 39)
F-test		11.79 (0.001)	1.83 (0.178)

Source: Household survey, 2019. In-between brackets: (std deviation, n).

TABLE 5 | Rice yield by seed type, irrigation status and study areas, Nepal (kg/ha, farmer reported).

		Nuwakot (mid-hills)	Chitwan (terai)
Rainfed	OPV	2,002	4,209
	Hybrid	2,949	5,120
Partial irrigation	OPV	3,056	4,209
	Hybrid	4,098	5,631
Full Irrigation	OPV	3,857	4,270
	Hybrid	5,246	4,686
F		9.69 (0.00)	4.90 (0.00)

Source: Household survey, 2019.

With respect to the status of irrigation in farmer's field in both the study areas, about 64% of the paddy plots were fully irrigated, while about 29% of the plots were partially irrigated, and 6% rainfed. Perception analysis of irrigation status suggests broad-based improvements over the last 10 years across all farm size groups ($F = 4.577$; $P = 0.00$). The results show that about 33% of the households are yet to benefit from irrigation development for rice production indicating scope to enhance paddy production by developing irrigation schemes.

Labor and Mechanization

The number of household members engaging in agriculture was reportedly reducing. At the same time, 83% of the households perceived farm wages to have increased over the last 10 years and a similar share perceived off-farm employment and income to have improved over the same period. Overall, for youths, the average years of schooling completed by males in Nuwakot and Chitwan was 5.67 (sd-7.8) and 9.74 (sd-9.4), respectively. In the case of females in the youth category, the average years of schooling completed in Nuwakot and Chitwan was 6.67 (sd-8) and 13.05 (sd-8.9) years, respectively.

During the group discussions farmers mentioned that labor is scarce and households in Chitwan employ seasonal workers from Siraha District of Nepal. In Nuwakot, laborers from remote village municipalities come to work in the rice fields. Farm activities such as tillage, sowing and planting, harvesting, threshing, transport, and storing were contracted to laborers over the growing season.

TABLE 6 | Farm equipment ownership in the study areas, Nepal (% households reporting).

	Nuwakot ($n = 96$)	Chitwan ($n = 198$)
Tractor	3	4.6
Power tiller	16.7	3
Pump set	19.8	94.5
Trailers	1	3
Sprayers	66.6	55

Source: Household survey, 2019.

The formal survey suggested that all farmers perceived that mechanization was increasing in response to labor costs and scarcity and 76% indicated that ownership of farm machineries had increased over the last 10 years. Discussion with local traders revealed that the sales of farm machinery and equipment's has been increasing in recent years, positively affected by supportive governmental subsidy programs. **Table 6** shows a cross section status of the ownership of farm assets in the study areas among the sample population. The most common farm machinery being used are small tractors, mini power tillers, trailers, pump sets, and sprayers. Due to the hilly nature and consequent small plot size, ownership of lightweight two-wheel tractor based power tillers was higher in Nuwakot while households in Chitwan had a higher ownership of four-wheel tractors. Bullock cart, traditionally used for hauling, has almost been replaced by tractors and trailers in both the locations. Importantly, both four- and two-wheeled tractors were commonly reported to be used to transport farms inputs and outputs, as well as construction materials, in both areas. Ownership of pump sets in Chitwan (34.5%) is higher than in Nuwakot. This is because of the ability to tap groundwater in the Terai, whereas in the hills, available water tends to come from surface streams transferred by gravity. Ownership of sprayers is high among households in both study areas.

Tractor owners rented services to other farmers at a fee of NRs 2,100/h (USD 19). Such "fee-for-service" provision is increasingly common in Chitwan, though formalized and well-organized markets for farm equipment services are yet to develop. Hiring was in most cases conversely based on one to one relationship between owners of equipment and their farmer-clients. With the growing road network, transportation services have developed and are helping farmers to haul bulk outputs and inputs between farms and markets using trailers pulled by two- and four-wheel tractors. In focus groups, farmers commented that road access has also expanded the services of traders who often come to the farmgate to purchase agricultural output and sell inputs to the farmers. Many tractor owners use the tractors and trailers to haul gravel, stones and sand during non-agricultural season.

Access to Markets and Marketing Surplus

The expanding road network had enhanced farmers access to markets and banks. Traveling to input and output markets had become easier and travel time reduced, and marginally more so in Chitwan than the hilly terrain of Nuwakot (**Table 7**). In Chitwan about 53% of the household indicated that they traveled

TABLE 7 | Average access time to markets in study areas, Nepal.

	Nuwakot (mid-hills)		Chitwan (terai)	
	Purchase	Sell	Purchase	Sell
<30 mins	36	52	53	53
30 mins to 1 h	49	38	43	43
More than 1 h	15	10	3	3

Source: Household survey, 2019.

<15 min to access an input or output market. In Nuwakot, while 52% of the households indicated that they accessed an output market in <15 min, only 36% indicated that an inputs market was within 15 min from their homes. Better access to markets in Chitwan than in Nuwakot is reflected by the fact that in Chitwan <5% indicated such markets to be more than 1 h from their homes. In Nuwakot this percentage was between 15% (input purchase) and 10% (sell output). A reason why relatively more households (overall 42%) indicated less time to access output than input market maybe because many (56%) of the households indicated that traders purchase produce at their farm gates. Most households in Chitwan use bicycles to access markets to sell or purchase inputs.

The households (72% in Nuwakot and 82% in Chitwan) indicated that the road quality from their locality to the nearest market center to sell and purchase farm products and inputs had improved over the last 10 years. This was also corroborated by an almost similar response from households from both the areas that travel time to market centers had decreased, but there was variation in travel time to markets across different partitions of the sample, given the disperse settlements found among the farming communities in both the study areas.

Less women headed households indicated that road quality had improved in Nuwakot (female heads 38% vs. male heads 81%) than in Chitwan (female heads 72% vs. male heads 85%, $F = 12.81$; $P = 0.000$). The results were however, not statistically significant for other variables, indicating that improved road quality benefits are relatively uniformly distributed. A majority (81%) also perceived that they received relatively higher prices for their agricultural produce.

Marketable surplus of all the farm products increased but farmers' perceptions varied. About 45% of the farmers in both Chitwan and Nuwakot indicated that marketable surplus of paddy increased over the last 10 years. The average income from paddy was between Rs 10,400 (USD 94.5,[2] Chitwan) and Rs 16,000 (USD 146, Nuwakot) among female headed households, while among the male households, the average income varied between Rs 22,000 (USD 200, Chitwan) and Rs 16,000 (USD 146, Nuwakot). There was no significant difference in the mean values of the marketable surplus across the above sample groups. Only in Nuwakot did the marketable surplus differ among farm size groups ($F = 24.27$; $P = 0.00$). There was no difference in the mean value of the marketable surplus across the educational groups in Nuwakot. In Nuwakot, the large farmers marketable surplus from rice were more than six times that of marginal farmers, but this was not the case in Chitwan, where the distribution of marketable surplus across these groups was relatively uniform. Despite lower yields on larger farms, these farmers had higher aggregate production due to the larger landholding. Another trend observed was that there was a negative relationship between paddy income and the education level of the household head. Farm families with more educated adults preferentially engaged in off-farm rather than agricultural work, leaving behind less educated adults in rural areas.

Access to Financial and Extension Services

About 68% of farmers surveyed reported to have opened accounts in the formal banking sector (Class A banks). Out of these, 44% had been opened accounts within the last 5 years and 9% indicated their accounts were more than 12 years old. About 37% indicated that they visited their bank at least once a month with most farmers visiting less frequently.

About 70% of the households indicated that their contact with agricultural input dealers was better now than a decade ago. The average ownership of mobile phones in Nuwakot and Chitwan was 2.45 and 2.91 per household, respectively, and considering household size of 3.58 and 4.3, respectively, the per capita ownership of mobile phone was high. All households across the farm size groups owned a television. Nonetheless, no households in Nuwakot indicated they use their mobile phones to obtain agricultural information. In Chitwan, however, between a quarter and one-half of surveyed farmers reported to have used their mobile phones to access agricultural information. Use of mobile phones was 42% higher among literate households. 80 and 56% of farmer respondents in Chitwan and Nuwakot, respectively, reported to watch agricultural programs broadcasted by the government on television. Significant differences by gender ($F = 9.09$; $P = 0.003$) and education ($F = 6.07$; $P = 0.000$) were observed in television viewership.

Enabling Environment for Rice Market Development

Discussion with millers and Miller Association representatives suggest that there are upwards to 1,000 rice mills in Nepal of various sizes, operating at 50% capacity due inconsistent paddy supply. Millers suggested that some 70% of imported rice (0.75 million tons) in 2019 consists of fine, aromatic grain, the demand for which is increasing in urban markets. Domestic production and sourcing of fine rice varieties however remains low. Nepali coarse rice not sold as grain was passed on to brewery and poultry feed industries. To address the consumers' increased demand for fine rice, the Ministry of Agriculture and Land Management (MoALD) has allowed the import of seeds of fine OPV rice varieties in the recent years. Five such varieties were registered in 2015 (Sinduri, Sundarm, Deltarani, Akash, and Ultra Super Sampurna). From 2017 to 2019, a total of 41 new rice varieties were notified including nine fine quality OPVs. Among these varieties, two varieties (Bahuguni 1 and Sugandhit Dhan 1) are the locally released varieties, and seven (Sawa Masuli, Mukwala 23, TMRH 1626, Ankur Jyotika, Shreeram

[2] 1 USD = Rs. 110.

TABLE 8 | Cost of production and inputs cost shares (%) by farm size group, Nepal.

Farm size group	Input cost shares in total production cost (%)				Cost (Rs/ha)
	Labor	Capital	Chemicals/ Fertilizers	Seed	
Marginal and small	0.53	0.27	0.10	0.10	103,732 (99,984)
Medium	0.49	0.30	0.11	0.11	118,927 (117,612)
Large	0.52	0.26	0.11	0.11	94,929 (99,265)
F-value (significance)	1.07 (0.02)	1.17 (0.31)	0.26 (0.77)	0.14 (0.87)	0.86 (0.042)

Source: Household survey, 2019. In-between brackets for cost per ha: (std deviation).

TABLE 9 | Cost of production and inputs cost shares (%) by study areas, Nepal.

Study Area	Input cost shares in total production cost (%)				Cost (Rs/h)
	Labor	Capital	Chemicals/Fertilizers	Seed	
Nuwakot	0.54	0.23	0.13	0.09	84,438 (44,533)
Chitwan	0.50	0.30	0.09	0.11	115,389 (103,522)
F-value (significance)	3.30 (0.07)	15.96 (0.00)	29.23 (0.00)	0.89 (0.35)	5.94 (0.01)

Source: Household survey, 2019. In-between brackets for cost per ha: (std deviation).

Khusbu, and black rice) varieties are the imported fine quality OP varieties.

Although several varieties of fine and medium fine rice varieties have been released in Nepal, millers were largely unaware of them. For this reason, millers were reluctant to pay premium price for grain of Nepali fine varieties produced by farmers. Millers also suggested that most processing machines are for coarse rice varieties. Although the milling recovery of fine rice varieties in existing mills is poor, millers are reluctant to invest in capital equipment to support increased and appropriate processing of fine rice.

Efficiency in Paddy Production

In our model, the cost of cultivation consists of four main inputs, namely labor, capital, chemicals/fertilizers, and seeds. **Tables 8**, **9** provide results of the cost of cultivation per ha across the three farm groups and study areas, respectively. Larger farms had slightly lower production costs than marginal/small and medium farms (**Table 8**). Nuwakot had markedly lower production costs than Chitwan (**Table 9**). The cost of (hired) labor accounts for the highest farm input cost share across all farm groups. While the cost of labor in Nuwakot was found to be higher than in Chitwan, the share of cost of capital is higher in Chitwan than in Nuwakot, reflecting the growing capital-labor substitution taking place in Chitwan (**Table 9**). The cost of capital includes the use of tractor, power tiller, pump set, and sprayer and comprises the second largest cost in paddy cultivation. The combined cost of labor and capital accounts for some 80% of the total production cost. The cost share of chemicals/fertilizers varies between the study areas (9% in Chitwan vs. 13% in Nuwakot, **Table 9**). The cost share of seed input is similar to that of chemicals/fertilizers. Like fertilizer, availability of improved rice seeds is often uncertain in the market.

For the stochastic frontier analysis (cost function) we hypothesize the four input groups (labor, capital, chemicals/fertilizer, and seed) to influence paddy output. Efficient farmers can produce more with the available inputs relative to less efficient farmers given the variable inputs used as per their socioeconomic characteristics. Only 197 farm households had complete information for carrying out the stochastic frontier analysis. **Table 10** presents the summary statistics of the variables used in the estimation of the stochastic frontier.

To capture this production process, Equations 2 and 4 are jointly estimated. The maximum likelihood estimates for the Cobb Douglas frontier function provided in **Table 11** shows that the generalized likelihood ratio test defined by the chi-square (X^2) indicates the presence of technical inefficiency.

The coefficients of estimated frontier function suggest that seed and chemical/fertilizer inputs are positive and significant implying that farmers are willing to pay more for better quality seeds and spend more on fertilizer. As was discussed earlier, there were still farmers (about 30% in Nuwakot and 40% in Chitwan) who indicated that adequate amount of fertilizer could not be purchased on time. Chitwan has distinct features in terms of market size, access to wider markets for inputs and outputs, banking services, transport networks. These features are expected to make Chitwan more efficient than Nuwakot as reflected by the negative region dummy (**Table 11**).

Male headed households are relatively more efficient than their female counterparts. Years of schooling reduces technical inefficiency, which is as expected. The human capital is negative and implies that farmers with greater experience in paddy

TABLE 10 | Descriptive statistics ($n = 197$).

Variables and explanation	Variable name	Units	Mean	Std. deviation
Paddy production related variables (Equation 3)				
Labor cost share	ln(labor cost)	%	0.50	0.19
Capital cost share	ln(capital service cost)	%	0.28	0.15
Chemical/fertilizer cost share	ln(chemical fertilizer cost)	%	0.11	0.08
Seed cost share	ln(seed cost)	%	0.11	0.14
Socioeconomic variables related to inefficiency (Equation 4)				
Study area dummy (Nuwakot = 0, Chitwan = 1)	REGION			
Gender of household head	GENDER	% of males	83.00	37.00
Years of schooling by household head	HHEDU	Years completed	7.89	4.68
Household size adult members above 18 years	HHSIZE	Number	4.15	1.57
Years of experience in growing paddy	YRSFARMP	Years	26.01	11.74
Time to reach market (minutes)	MKTIME	Minutes	19.18	13.03
Land fragmentation	FRAGMENT	# of parcels	1.64	0.99
Years since having account in commercial bank	BANKAGE	Years	6.74	3.12
Rice cultivated area	RICEHA	Ha	0.59	0.61

TABLE 11 | Stochastic frontier model.

Dependent variable: Natural log of total paddy output (kg)		
Independent variables		
Productive inputs:		
	Coef.	***t***
Seed Cost (Rs)	0.208	4.24**
Chemical fertilizer cost (Rs)	0.095	2.32**
Capital service cost (Rs)	−0.041	−1.37**
Labor cost (Rs)	0.047	1.30**
Constant (b0)	5.402	11.21**
Constant (d0)		
Inefficiency effects:		
REGION (0 = Nuwakot, 1 = Chitwan)	−1.199	−9.83**
GENDER of household head (female = 0, male = 1)		
HHEDU (Years of schooling household head)		
HHSIZE (household size members > 18 years)	−1.115	−1.95*
YRSFARMP (years of experience in paddy farming)	1.904	2.11**
MKTIME (time to reach market in minutes)	−0.125	−1.84
FRAGMENT (land fragmentation)	0.19	1.00
BNKAGE (years having bank account)	−0.118	−3.11
RICEHA (rice cultivated area, Ha)	0.04	2.22
Random error constant (d0)	0.905	2.69**
Constant (w)	−0.037	−0.50
Wald chi2(4) =	−7.302	
Log likelihood=	1.609	
Prob > Chi2 =		

*$p < 0.01$.
**$p < 0.05$.

farming are technically more efficient than farmers with less experience. Access to market, as expected, is positively associated, indicating the importance of improved access to rice productivity. As area under paddy decreases, farmers are unable to exploit the economies of scale due to inability to purchase certain inputs such as chemical fertilizer in bulk at lower cost, unprofitability to purchase farm equipment given the small size rice area cultivated, transportation cost of inputs and output from and to market etc. Thus, larger area cultivated enhances efficiency in rice production. The sign of the land fragmentation coefficient has a positive sign indicating that fragmentation is associated with inefficiency in production. Fragmentation leads to increased overall production costs and hence inefficiency increases.

These results indicate that, on average, paddy farmers are only able to achieve about 76% of potential maximum output from the given productive resources available to them (**Table 12**). The estimated efficiency scores were also analyzed across the household's head's gender, education class and farm size groups. Technical efficiency across the paddy farmers in Nuwakot (0.763; sd 0.207) and Chitwan (0.752; sd 0.192) does not show much variation. Technical efficiency among farmers within each study area is thinly spread as indicated by the low values of the standard deviations. The results also show that there are no differences in the estimated values of technical efficiencies between male and female headed households and between the education classes of the paddy farmers (**Table 12**). However, when examined across the farm size groups, small/marginal farms were relatively less efficient than the other two groups.

DISCUSSION AND CONCLUSIONS

In Nepal, an improved technical efficiency overhaul within agriculture remains is a development priority (Paudel and Wagle, 2020). Measuring efficiency is one of many approaches to assess farmers' capacity to allocate resources (land, labor and capital) to improve productivity and identify factors influencing (in)efficiency that can be addressed through agronomic management and supportive policy and development

TABLE 12 | Distribution of efficiency scores across paddy farmers by various sample partitions, Nepal.

Sample partitions		Mean efficiency	Std. Dev.	sample size	*F*	Sig.
Study area	Nuwakot	0.763	0.207	73	0.139	0.71
	Chitwan	0.752	0.192	124		
Household head	Female	0.770	0.200	33	0.193	0.66
	Male	0.754	0.197	164		
Household head- years of completed schooling	Illiterate	0.811	0.180	21	0.948	0.45
	Literate-no formal schooling	0.829	0.166	14		
	Primary completed	0.758	0.201	27		
	Medium completed	0.753	0.200	35		
	High school	0.732	0.214	79		
	Higher level	0.748	0.149	21		
Farm size group	Marginal & small	0.66	0.18	103	45.88	0
	Medium	0.81	0.13	50		
	Large	0.92	0.14	44		

actions. We found a similar technical efficiency across paddy farmers of 76% in our two contrasting study areas, Nuwakot in the mid hills and Chitwan in the terai. Piya et al. (2012) found technical efficiency of rice farmers 67% in Dhading and 74% in Chitwan while carrying out a survey about 10 years back. Similarly, Khanal and Maharjan (2013) found a quite high technical efficiency of rice seed growers' farmers from Chitwan (85%). Moreover, Kyi and Oppen (1999) found average efficiency of farmers was 88%, ranging from 39 to 93%, in irrigated rice of Myanmar. Idiong (2007), shows Nigerian rice farmers were 77% efficient, ranging from 48 to 99%.

The efficiency of farmers could still increase further, particularly in the tail end of the distribution and for the marginal and small farm sizes. Yet agricultural transformation is not only about the more efficient use of these productivity factors; it also addresses the need to create an enabling environment to support sustained change over time. Results indicate that many factors that can influence agricultural transformation process such as access to improved seeds, irrigation, extension services, productivity, marketable surplus, and access to markets has improved in the study areas. Farm labor is rapidly moving out to the non-farm sector, farm mechanization is on the rise, agricultural investment funds are being made available to farmers and the road network has improved. Growth in access to information technologies and particularly mobile phones is enabling farmers in Chitwan to innovate and increase farm productivity. Improving mobile networks in the hills is a priority to improve access to information.

Cereals currently are and will continue to be major staple food in Nepalese diet (Krupnik et al., 2021). Fine rice demand constitutes one-fourth of total rice demand in Nepal and coarse rice demand is projected 3.5 Mt by 2025 and to rise to 4 Mt by 2035 (Kumar et al., 2020). Our results suggest that poor access to necessary inputs and farmers' socioeconomic characteristics are some of the factors preventing the achievement of improved efficiency in rice production. Labor was identified as a major constraining factor, in line with considerable literature on this topic in Nepal (Gartaula et al., 2012; Bhandari and Ghimire, 2016). Yet despite its largest share in the cost of production, our models suggested that availability of household members was unlikely to be effective in increasing technical efficiency in production. The increasing level of education among youths, and off farm employment opportunities, explains youth's preference to work off farm, even if they live in the farm households. This may be because work in the non-farm sector is more preferred, and income is relatively better. Labor scarcity is pushing up wages (Paudel et al., 2019), and farmers face increasing challenges in accessing labor when and where it is needed, particularly for labor-intensive paddy production operations like transplanting and harvesting. A potential policy option to address this challenge is to incentivize domestic investment in agriculture and more crucially, channel foreign direct investment in agriculture with an appropriate minimum wage to help curtail the large-scale out-migration that occurs annually in Nepal as laborers seek more remunerative employment abroad (Paudel and Wagle, 2020). The wage gap between agriculture and the non-agricultural sectors does not appear to be very high and based on the National Salary and Wage Rate Index, the agricultural laborer wage index has remained higher than the industrial or the construction sector laborer wages. However, agricultural employment is seasonal and with higher education, youths prefer to work in the non-agricultural sector or seek foreign employment, which generally are full time. There is a need for additional research on unorganized labor markets and access to smallholder farm households.

Despite constituting a significant portion of the farmers' paddy cultivation budgets, there is great uncertainty in the availability of capital inputs. Farmers are unable to plan production and depend on hiring services. The low frequency of the use of bank services by households indicates that financial transactions in agricultural sector may still be governed by cash or informal borrowings rather than through the formal banks. While the GoN of Nepal has incentivized the access to loans for small machineries it is still not accessible (financial and physical) to the small holders farmers. It is important to encourage the private sector led custom hiring services in rice producing areas that are already facing labor shortages.

As agricultural transformation progresses it is important to understand the reasons for farm level inefficiency. Result from the technical efficiency across farm size groups shows a positive relation between technical efficiency and farm size. Land size is directly related with economies of scale which will enable farmers to use capital and other inputs more effectively to enhance their efficiency. Some reasons for the diseconomies of scale faced by the smaller farmers could be weak bargaining power in negotiating labor contracts or hiring farm machines, transport, and transaction costs etc. Access to financial resources are less available to smaller farmers relative to the larger farms and even if available these farms have to rely on informal financial markets where interest rates are higher. While the prominence of agriculture is declining, the number of farms is increasing, and the average farm size is decreasing (Paudel and Wagle, 2020). Hence, having larger farms, relative to present size, can help farmers reduce inefficiency. The GoNs interest in land consolidation and cooperative farming can thus be useful in increasing efficiency.

With the recent changes in the administrative structure of the country, which emphasizes urbanization, the connection between rural and urban areas is also likely to further develop and strengthen the relationship among farmers, millers, service providers consumers, and other stakeholders. Small market towns are also an important element for AT. They perform functional linkages by serving as nodes for food producers and processors many of whom lack other livelihood options (Tacoli, 2017). They serve as providers of goods and services and employment opportunities through processing and value addition to surrounding rural areas in addition to its own. Resulting employment opportunities can be especially important for seasonal agricultural labor and reduce outmigration.

There is a need to adopt a market system development approach to support small holder farmers to generate efficiency. A strong coordination between market actors involved in the farm to table chain for rice needs to be promoted with the facilitation of GoN programs. Further commercialization of agriculture is the need of the hour and there is a need for a strong private sector led service delivery system for production, agronomy, post-harvest and processing (Kumar et al., 2020). A dynamic private sector has been recognized as important for driving productivity, growth, and creating value and jobs in supply chains (Ferroni and Zhou, 2017). Technologies from private research including but not limited to advances in plant genetics and seeds, fertilizers and plant protection etc. has contributed to agricultural development (Pray and Naseem, 2007). Private sector is also important in food processing, wholesale and retail industries (Dubbeling et al., 2016; Ferroni and Zhou, 2017). Such service provides choice to consumers and also helps create jobs, investment opportunities, intra-industry linkages, and opportunities to link farmers to markets.

The extension services need to facilitate the process of building bridges between local and scientific knowledge, and promote site-specific, tailor-made sustainable production systems (Joshi and Joshi, 2020). Access to information also plays an important role in AT. Farmers who have access to extension services and information can improve their knowledge on improved crop and livestock breeds, production techniques, and administrative procedures of obtaining loans and land acquisition, weather forecasts etc. and hence, can make informed decision (Ullah et al., 2016). There is a need to engage youth in upgraded market systems by supporting the growth of agro enterprises along the value chain. Improving agricultural productivity is undeniably crucial to the growth of rural and national economies. Promoting this transformation requires creating markets where they are missing or weak, supporting economies of scale, and expanding and deepening rural banking, insurance, and financial systems (Thapa et al., 2020b).

The input market systems need to be further developed in Nepal. The national research system is underfunded at present, and challenged to generate technologies required for diverse enterprises, ecological settings, and different categories of farmers (Ghimire et al., 2015; Joshi and Joshi, 2020). The growing economy, structural change and people's increased preference for fine rice should be addressed in the rice research and development strategies. There is a need to develop industry preferred varieties and facilitate their multiplication by seed companies (Gairhe et al., 2021). The supply of imported varieties is sometimes challenged with irregular supplies of farmers' preferred varieties, border disruptions and also COVID-19 related supply chain distortions. Hence a strong domestic seed sector as envisaged by the National Seed Vision of the GoN is imperative. Similarly, although the budget for importing fertilizers has been increased by the GoN, there is still a shortage and inadequate supply for rice production (Ghimire et al., 2015). The procurement process for fertilizers must be improved with establishment of buffer stocks to meet the demand during peak season. Additionally, the private sector may be encouraged to import and meet the deficit in fertilizer supplies. Nepal needs to continue to enhance its food security by increasing the public investment in irrigation, rural infrastructure and rapid spread of modern technology with improved food production practices (Kumar et al., 2020). Adhikari et al. (2017) also point out that higher temperature and erratic rainfall, might have negative impact in future paddy yields. Devkota and Paija (2021), highlight the importance of developing stress tolerant rice varieties. Devkota et al. (2018) highlighted capital inadequacy, high cost of agricultural inputs, poor access to adaptation information, inadequate access to credit facilities and inadequate awareness about adaptation as barriers to adapt to a changing environment in Nepal. In the context of the COVID-19 related changing labor market and reducing income from remittances, agriculture may provide a more important source of economic growth through agricultural transformation and farmers adaptation.

In the end, efforts must be made to ensure the agricultural development is inclusive and equitable, and includes both women, men and youth and disadvantaged communities and regions. AT also can have heterogeneous implications—e.g., changing roles for women involved in weeding and harvesting (Team and Doss, 2011; Akter et al., 2017). Men are also migrating to rural non-farm and urban areas within and outside of Nepal, increasing the responsibilities of women and feminization of agriculture (Gartaula et al., 2017). There remains an imbalance in access to resources such as finance and services for females relative to males. Our two study areas—albeit contrastingly located in the mid hills and terai—are still relatively centrally located in Nepal and compared to other geographies, have a reasonable access to markets and services. More remote areas may have even more disproportionate challenges in terms of access to seed and fertilizers, information technology, transportation, education, services, and markets.

The research findings have implications on overall food security in the country and South Asia. As it stands now, the role of the agricultural system in ensuring food availability is the dominant research topic currently bridging agricultural systems and food security concerns (Stephens et al., 2017). In recent years, a more holistic concept of a "food system" has gained traction amongst both scholars and policy-makers with a perspective that integrates all the elements (environment, people, inputs, processes, infrastructures, institutions) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes (Béné et al., 2019).

Hunger and malnutrition are likely to rise in 2020 as the pandemic impacts all aspects of food systems. To reduce the impact of such shocks in the long term, there is a need to build more resilient and inclusive food systems (Fan and Swinnen, 2020). Increasing women's decision-making power and control over assets within their households and communities is a key step toward inclusive food systems (Malapit et al., 2020). These authors also point out that youth are also marginalized in many countries, lacking sufficient employment opportunities, land if they choose to stay in agriculture, and financial capital if they attempt to enter the rural non-farm economy. Better integrating small holders farmers including youth and marginalized communities into national food systems, by linking subsistence-level farmers to markets is perhaps the most effective way to achieve inclusive economic growth (Fan and Swinnen, 2020). Understanding better food system drivers—both what they are and how they function—is therefore one of the first steps toward supporting policy-makers at the global, national and subnational/municipality levels in designing and implementing appropriate policies and interventions (Béné et al., 2019).

Investment needs and potential economic synergies are probably best addressed through a territorial or geographic approach such as agro-industrial parks, agro-based special zones, incubators, clusters, and agro-corridors (Vos and Cattaneo, 2020). There is a need for developing an evidence-based targeting strategy and develop adequate infrastructure and public and private sector investments in such areas with advantages in returns on investments. Public programmes such as the Prime Ministers Agriculture Modernization project can develop appropriate strategies in the designated rice "super" zones for making available quality seeds, processing facilities and equipment services to extend the reach and benefits of agricultural transformation.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Research Ethics Committee, CIMMYT. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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