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Article

Impact of Irrigation Method on Water Use Efficiency and Productivity of Fodder Crops in Nepal

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Abstract: Improved irrigation use efficiency is an important tool for intensifying and diversifying agriculture in Nepal, resulting in higher economic yield from irrigated farmlands with a minimum input of water. Research was conducted to evaluate the effect of irrigation method (furrow *vs.* drip) on the productivity of nutritious fodder species during off-monsoon dry periods in different elevation zones of central Nepal. A split-block factorial design was used. The factors considered were treatment location, fodder crop, and irrigation method. Commonly used local agronomical practices were followed in all respects except irrigation method. Results revealed that location effect was significant ($p < 0.01$) with highest fodder productivity seen for the middle elevation site, Syangja. Species effects were also significant, with teosinte (*Euchlaena mexicana*) having higher yield than cowpea (*Vigna unguiculata*). Irrigation method impacted green biomass yield (higher with furrow irrigation) but both methods yielded similar dry biomass, while water use was 73% less under drip irrigation. Our findings indicated that the controlled application of water through drip irrigation is able to produce acceptable yields of nutritionally dense fodder species during dry seasons, leading to more effective utilization and resource conservation of available land, fertilizer and water. Higher productivity of these nutritional fodders resulted in higher milk productivity for livestock smallholders. The ability to grow fodder crops year-round in lowland and hill regions of Nepal with limited water storages using low-cost, water-efficient drip irrigation may greatly increase livestock productivity and, hence, the economic security of smallholder farmers.

Keywords: Irrigation efficiency; drip irrigation; forage biomass; Nepal

1. Introduction

Agriculture is one of the most susceptible sectors to climate change [1], with livestock production being the most climate sensitive economic area [2]. Climate change may adversely affect various aspects of livestock production systems including animal health and productivity, fodder production, water availability, pests, and diseases [3]. The livestock sector—an integral part of the mixed farming system of Nepal—is facing adverse impacts from climate variability and extremes [4,5]. Smallholder farmers with low income are a large and particularly vulnerable group. Precipitation analysis indicates that there has been a tendency toward more frequent and intense droughts during the dry season over the past decades in the Gandaki River Basin (GRB) region of central Nepal [5,6]. Western Nepal has also experienced consecutive and worsening winter droughts since 2000, culminating in a severe drought episode during 2008–09 [7]. The summer monsoon (June–September) is the main rainy season, contributing around 80% of the annual rainfall. However, the spatial and temporal distribution of monsoon rainfall in the region has become erratic in recent years [6–9]. As most agriculture in Nepal is rain-fed, these changes pose a significant threat to agricultural production.

The topography of Nepal is rugged, and although large rivers frequently cause flooding events, insufficient water for farming often occurs due to lack of infrastructure for water storage and irrigation. Rainfed cultivation and traditional irrigation have served farms and farmers well in the past. Water applied using these systems supported the growth of annual and perennial fodders, yielding a cost effective production system. In recent years, rising temperatures, more variation in summer and winter temperature, erratic rainfall, and prolonged droughts, along with steady growth in human and livestock populations (Figure 1), have resulted in reduced supply and increased cost of irrigation water and other pressures on perennial pastures, forcing farmers to consider alternative land uses and irrigation systems [10]. This has created an increased reliance on annual crops and fodders purchased from outside the farm at higher cost compared to home-grown feed to fill feed gaps.

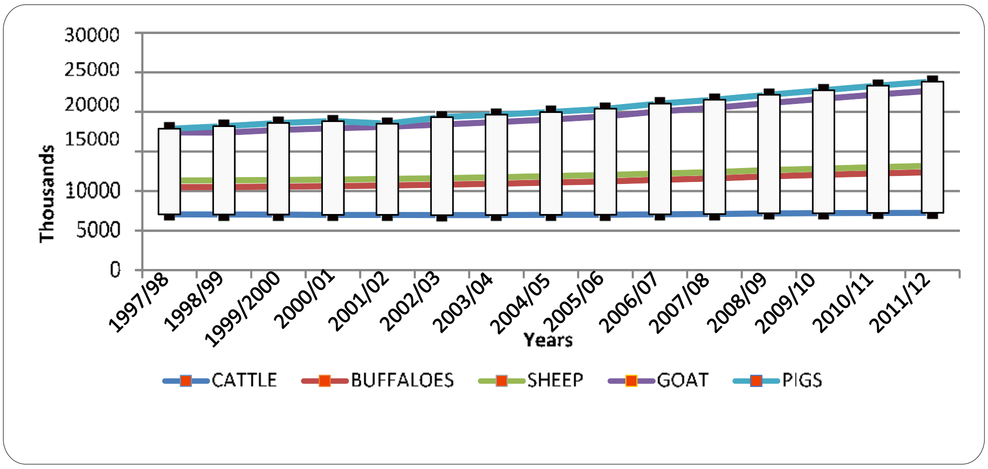

Figure 1. Trends in population of major livestock species in Nepal [11].

Furrow irrigation is the dominant method of water delivery in Nepal. Furrow irrigation, a system where water is transferred from a head ditch to crop furrows via siphons, is one of the simplest and most ancient forms of irrigation delivery [12]. It can achieve reasonable irrigation efficiency (IE), although this can be highly variable. The efficiency of furrow irrigation is affected by field slope and length, and by water infiltration rates. Control of the rate of irrigation application and reduction in drainage beyond the root zone is difficult. With water delivered by inundation of furrows, waterlogging is common [13]. In slopes, a greater amount of water is supplied to the upper portion of the field, which increases deep water drainage beyond the root zone, depriving the root zones of plants at the lower end of the field of full recharge. Heavy or prolonged water application can result in excessive runoff, while low rates of application tend to result in slow water advance, causing poor water distribution and deep drainage losses. Soil type and heterogeneity in infiltration rates both across and down the field also affect the efficiency of furrow irrigation. Soil crusting can be problematic in furrow irrigation systems, as soil slaking can result in bed deformation and slumping. Tail water losses, deep drainage, and evaporative and drainage losses from irrigation channels constitute predominant water losses from furrow irrigation systems. Furrow irrigation, although inherently limited, is a reliable and flexible system that can be managed to achieve reasonable IE. Furthermore, such a system encourages deeper crop rooting depths that utilize water from the entire soil profile.

Compared to furrow systems, drip irrigation can substantially improve water use efficiency (WUE) by minimizing evaporative loss of water and maximizing capture of in-season rainfall by the soil profile [14]. The main disadvantage of drip irrigation systems is the cost of installation and maintenance. Historically, irrigation scheduling in drip irrigation systems has proved to be slightly more difficult than for other irrigation delivery methods [15,16]. Nevertheless, drip irrigation can help satisfy the demands associated with increased pressures of growers to increase WUE and maximize production [15].

Precipitation in mountain regions is often highly variable, and efficient irrigation is the best approach for managing limited water supplies and irregular precipitation events. Surface drip irrigation slowly releases water directly to the roots of crops, saving 60%–70% in water consumption and reducing the chance of disease infestation as waterlogged plants are susceptible to fungal and other diseases [17]. This system of irrigation keeps the topsoil layer moist but not excessively wet, and can be used to provide the exact amount of water required to the plants [18]. One of the major challenges faced by livestock farmers in Nepal is obtaining fodder due to lack of rainfall and water availability outside the monsoon season. We propose that this problem can be minimized by adopting efficient irrigation technologies [18,19], such as drip irrigation, for cultivating nutritious fodder varieties during the dry season.

In the small farming system, IE is the fraction of water applied that is available to the crop, in the crop root zone, for uptake. Nutrients such as nitrogen (N), phosphorus (P) and potassium (K) are also critical for maximizing yield of fodder crops. Thus, soil testing is essential to determine the nutritional status of the soil, which dictates the management approach to maximize yields.

Given these considerations, the objective of this study is to evaluate WUE and soil nutrient levels as a function of irrigation system (drip *versus* furrow irrigation) when growing nutritional fodder crops in livestock smallholders' fields during the dry season. This research is important for effective utilization of available land, fertilizer and water especially in dry districts and seasons of Nepal for nutritional fodder production. The strategies tested have the potential to keep livestock smallholders resilient to the stresses caused by ongoing climate change.

2. Study Area and Methodology

Field experiments were conducted at farmers' fields from March 2013 to July 2014 at three locations representing various agro-ecological zones of the GRB in Nepal: Baireni village of Dhading district (highland); Tindobate of Syangja district (mid-hills), and Jayanagar of Kapilvastu district (lowland). The GRB area covers 31,100 km^2 in Nepal. (Figure 2). The Dhading, Syangja and Kapilvastu field sites had altitudes of 583, 780 and 126 m, respectively.

The soils of Nepal are very variable and are derived mainly from young parent material [20]. Soils in Nepal have been classified on the basis of soil texture, mode of transportation, and color, and are broadly divided into alluvial, sandy, gravelly, residual, and glacial types. Alluvial soil is found in the valleys of the Terai region and in the middle hill valleys around Kathmandu and Pokhara. The soil type were mostly sandy and silty alluvial in all the field locations.

We compared the effect of drip and furrow irrigation on the productivity of common nutritional fodder species using a split-plot design. The factors considered were three sites (Dhading, Syangja, Kapilvastu, representing different elevations and ecological zones in the GRB); two fodder crops (teosinte and cowpea); and two irrigation systems (drip and furrow). Fodder biomass (green and dry weight) was the main measured outcome. Except for the irrigation system, commonly used agronomical practices were followed in all the plots.

To determine biomass (over-ground) green (fresh) weight, green fodder from 1 m^2 of each plot was cut and weighed immediately on site. Five hundred gram samples from the fresh biomass were then dried for 24 hours at 70 °C in an oven and weighed to determine dry weight. Two sample cuts of biomass from each plot were averaged.

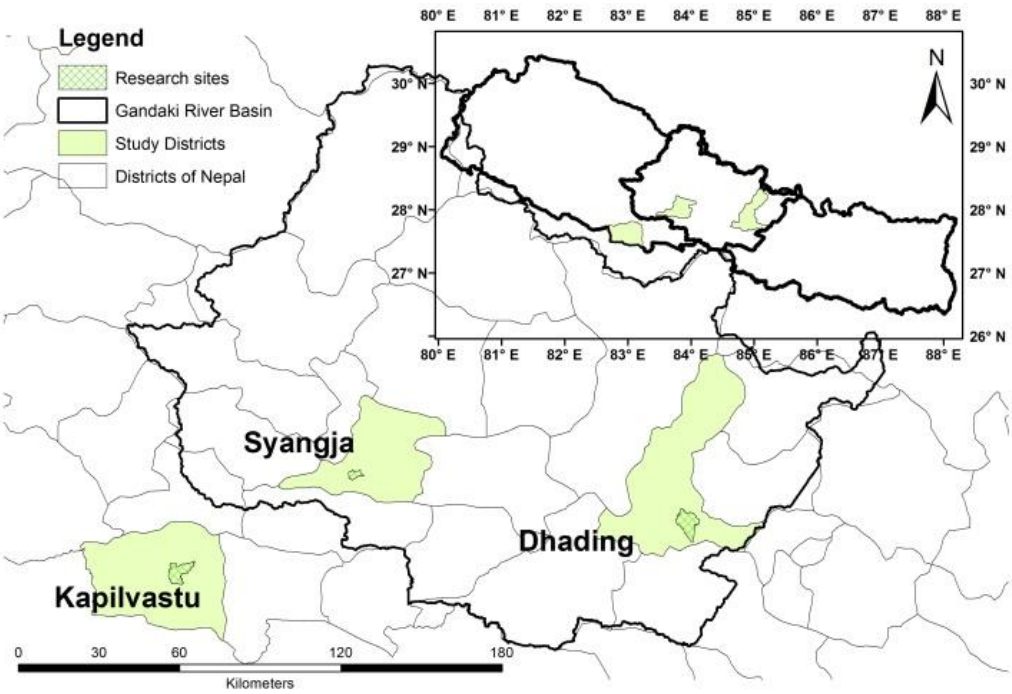

Figure 2. Gandaki River Basin, Nepal, showing locations of field sites.

Meteorological conditions: Rainfall and maximum and minimum air temperatures were measured using automatic weather stations installed at each site from 2013 to 2014 (Figures 3–5). The period from March–May is hot (especially in the lower-elevation Kapilvastu site) and quite dry, while the summer monsoon normally begins in the early part of June.

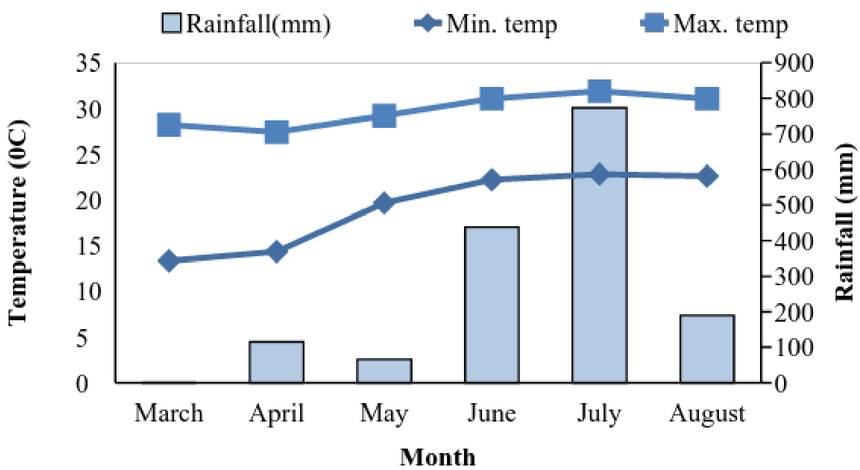

Figure 3. Monthly observed rainfall and mean maximum and minimum temperatures during the 2013–14 growing seasons at the experimental site in Syangja, Nepal.

Soil measurements: Five soil samples from 15–20 cm deep were taken using a core sampler from each site before sowing, and combined to make a composite site sample. These samples were air dried in shade for three days and mixed thoroughly, with any debris removed. Soil's physical and chemical characteristics measured included texture, pH, total organic matter, total nitrogen (N), available phosphorous (P_2O_5), extractable potash (K_2O), field capacity (FC), permanent wilting point (PWP) and bulk density (BD). For analyzing organic matter, soil samples were passed through a 0.5 mm sieve, and 500 g of sample was kept in a plastic bottle for further analysis. The soil properties at the experimental sites and the analysis methods are presented in Table 1.

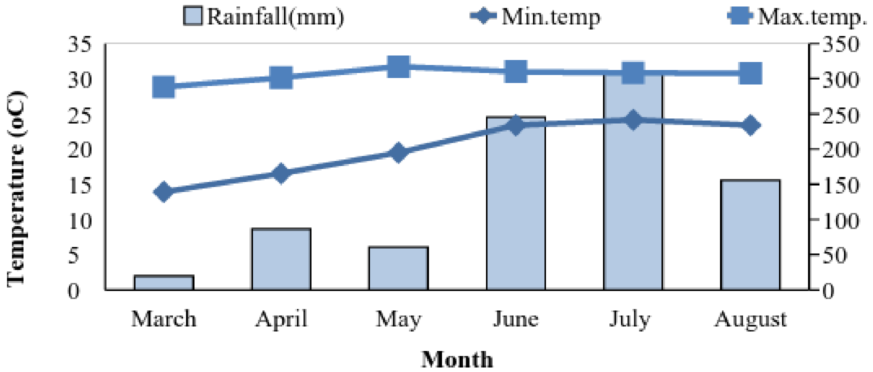

Figure 4. Monthly observed rainfall and mean maximum and minimum temperatures during the 2013–14 growing seasons at the experimental site in Dhading, Nepal.

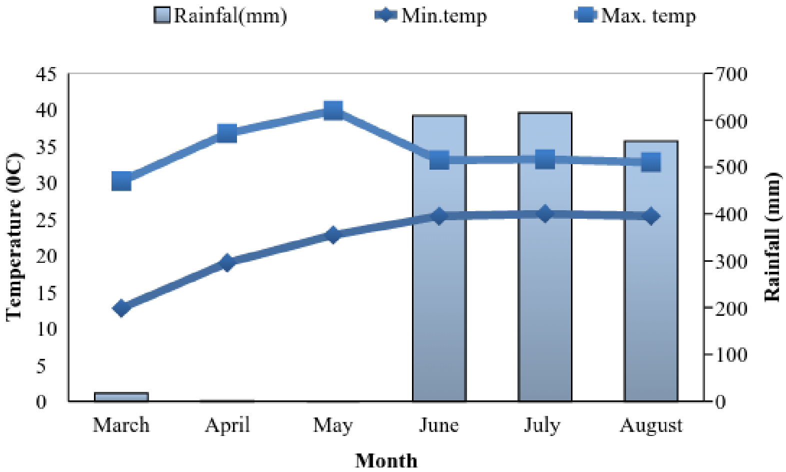

Figure 5. Monthly observed rainfall and mean maximum and minimum temperatures during the 2013–14 growing seasons at the experimental site in Kapilvastu, Nepal.

Table 1. Soil properties collected from experimental sites.

Experimental Site	pH	OM (%)	Total N%	P_2O_5 (kgha^{-1})	K_2O (kgha^{-1})	Sand (%)	FC (%)	PWP (%)	Silt (%)	Clay (%)	Text	BD (gcm^{-3})
Kapilvastu	7.1	0.53	0.05	40.0	94.3	38.3	16	29	37.5	24.1	L	1.37
Syangja	6.9	0.77	0.06	42.5	176.5	42.5	12	24.6	38.0	19.4	L	1.41
Dhading	5.1	1.2	0.07	7.5	103.4	49.0	13.3	25	29.5	21.4	L	1.41

L: loam, OM: organic matter, FC: field capacity, PWP: permanent wilting point, Text: Texture of soil, BD: bulk density.

The experiment was laid out in a split plot design and with six total treatments on each site. Each treatment was replicated four times, resulting in a total of 24 plots. Each individual plot measured 3m in length and 2 m in width. There was 0.5 m spacing between each plot and the main plots were separated by 1 m. There were 6 rows in each plot, with spacing of 0.25×0.50 m^2. The outermost two rows of both sides of each plot were considered as border rows to study the impact of intercropping cowpea and teosinte compared to growing them separately.

The two nutritious fodder species considered for growing with irrigation during the dry season were cowpea and teosinte. Cowpea (*Vigna unguiculata*) is a leguminous fodder crop typically grown below 500 m altitude as a pure crop or in mixture with maize, teosinte or napier-bajra hybrid. Cowpea is a crop well adapted to warm weather where there is limited rainfall. The crop is grown in semiarid regions of tropics and sub-tropics. Forage teosinte (*Euchlaena mexicana*) closely resembles maize and has preferential characteristics like profuse tillering, multi cut, high yield, and nutritional value. It is a tall and vigorously growing crop. It is comparatively less nutritious and palatable than maize, but due to its profuse tilling capacity it gives very good fodder yield. Teosinte can tolerate moderate drought and temporary flooding caused by heavy monsoon showers. Normally, it does not lodge. There is little difference in water requirement between the two crops, with both being well adapted to warm weather and limited rainfall and commonly grown in semiarid regions of the tropics and sub-tropics.

Irrigation schedule: Water was applied at the rate of 80 Liter per day (4 Liter per minute for 20 min) on the drip treatment plots, while, based on prevailing local practice, furrow treatment plots were inundated with 200 Liter per day. The plots were not irrigated on rainy days or on other days when there was sufficient moisture. The irrigation scheduling strategies implemented were intended to prevent over-application of water while minimizing yield loss due to water shortage or drought stress.

Water use efficiency: WUE (kg/m^3) of drip and furrow irrigation systems was calculated by the formula:

$$\text{WUE}\,(\text{kg/m}^3) = \text{Y/WR}$$

where Y = Yield (dry matter) of crop (kg/ha),

$$\text{WR} = \text{Total water consumed for crop production}\,(\text{m}^3/\text{ha})$$

Manure and nutrient management: To supply nitrogen (N), phosphorus (P) and potassium (K) at 60:40:40 kg/ha for cowpea and 120:60:40 kg/ha for teosinte, fertilizers were applied at all the sites. Urea, single super phosphate (SSP) and muriate of potash (MOP) were used as sources of fertilizer for supplying these recommended amounts of N, P, and K, respectively.

Statistical analysis: The recorded data were subjected to analysis of variance and Duncan's Multiple Range Test (DMRT) for mean separations. MSTAT-C Microsoft word computer programs was used for running statistical analysis. ANOVA was used to compare multiple factors and field conditions, and indicate whether the difference between multiple sample means across each factor (location, irrigation method, crop) were significant at the 5% level.

3. Results and Discussion

3.1. Dry Matter Yield

Cumulative forage dry matter production was significantly different from site to site ($p < 0.01$, Section 3.4.1). The highest yield was observed in Syangja (6942 $kgha^{-1}$), followed by Dhading (5651 $kgha^{-1}$) and Kapilvastu (3009 $kgha^{-1}$). Visually, the tallest and most profuse tillerings were also observed in Syangja. This difference is likely due differences in climate and in native fertility status of the soil between locations. The relative yields were affected by the crop species: Kapilvastu had the highest yield for cowpea, but the lowest yield for teosinte (Table 2).

Effect of irrigation methods on dry matter yield was non-significant ($p < 0.01$, Section 3.4.1), with about 7% higher mean yield recorded for drip irrigation. This was similar to earlier studies [16], where drip irrigation method produced similar or higher yields compared to conventional irrigation methods.

The effect of cropping system on dry matter production was significant ($p < 0.01$). Monocropped teosinte produced the highest dry weight, followed by mixture of teosinte and cowpea. The lower yield seen here for intercropping may be due to intercropping depressing the tillering ability of the teosinte (Table 2).

Table 2. Interaction of location and crop species for biomass production.

Interaction	Total Nitrogen (%)	Available P_2O_5 ($kgha^{-1}$)	Exchangeable K_2O ($kgha^{-1}$)	DM Production ($kgha^{-1}$)
Kapilvastu*Cowpea	0.068	93.179	89.519	2410 ^{cd}
Kapilvastu*Cowpea/Teosinte	0.074	87.794	91.509	2844 ^{cd}
Kapilvastu*Teosinte	0.068	86.604	90.845	3773 ^{c}
Syangja*Cowpea	0.074	103.864	176.651	2249 ^{cd}
Syangja*Cowpea/Teosinte	0.073	95.223	176.524	9142 ^{a}
Syangja*Teosinte	0.073	94.806	174.984	9435 ^{a}
Dhading*Cowpea	0.088	17.407	114.729	1195 ^{d}
Dhading*Cowpea/Teosinte	0.084	15.156	112.179	6360 ^{b}
Dhading*Teosinte	0.095	16.105	113.299	9397 ^{a}
LSD	Ns	Ns	Ns	1831 **
SEm±	0.0028	0.325	1.180	638
CV%	10.28%	1.36%	2.63%	24.72%
Grand mean	0.07	67.79	126.93	5200

Means in the same column followed by the same letter (a, b, c, d or cd) are not significantly different ($p > 0.05$). NS: Not significant. *: site specific crops. **: Significant at $p < 0.01$.

3.2. Green Biomass Yield

Combined green biomass weights of teosinte and cowpea fodder were highest in Kapilvastu and lowest in Dhading ($p > 0.05$). Green biomass weights of teosinte and cowpea were however statistically similar ($p > 0.05$) for Syangja and Kapilvastu and for Kapilvastu and Dhading, respectively (Table 3).

Table 3. Green biomass accumulation (kgm^{-2}) of teosinte and cowpea at different locations in Nepal during 2013–2014.

Location	Green Biomass Production (kgm^{-2})	
	Teosinte	Cowpea
Kapilvastu	9.169b	5.098a
Syangja	8.449ab	4.591ab
Dhading	7.511b	4.099b

Irrigation type influenced the green biomass weight of both teosinte and cowpea ($p < 0.05$). Drip irrigation produced lower green fodder yield for both species (Table 4), with overall green crop yield 13% higher for furrow than drip irrigation.

Table 4. Effect of irrigation type on green biomass production (kgm^{-2}) of teosinte and cowpea, in three locations of Nepal during 2013–2014.

Irrigation	Green Biomass Production (kgm^{-2})	
	Teosinte	Cowpea
Furrow	8.809a	4.978a
Drip	7.943b	4.213b

3.3. Irrigation Water Consumption

In furrow irrigation, water runs in small, parallel channels (furrows) between crops that are usually planted on ridges between the furrows. Although furrow irrigation provides reasonable IE, the overall performance of this system is influenced by several factors including field slope, length of run, soil type, water infiltration rates, length and rate of application, as well as evaporative and drainage losses.

Drip irrigation systems are often used in arid or semi-arid environments to improve WUE, and are valuable production tools in areas where water is limiting. This irrigation method has several advantages over furrow systems, including reduced water use, ability to apply fertilizer through the drip system, more precise water distribution, and reduced soil-borne diseases and weed growth as row middles remain drier than with furrow irrigation [21]. The increased water efficiency in drip irrigation systems is generally related to reduced soil percolation and surface evaporation as compared to other irrigation systems.

Total volume of water applied to the crop under furrow irrigation was 1419, 1972 and 2169 m^3/ha in Kapilvastu, Syangja and Dhading, respectively. Similarly, total volume of water applied under drip irrigation at those locations was 553, 394 and 542 m^3/ha, or on average 73% less than the furrow irrigation (Figure 6). These results indicate that total volume of water used under drip irrigation system was much less compared to furrow irrigation system. As the yields were similar, these results demonstrate that WUE (kg/m^3) is enhanced in drip irrigation compared to furrow irrigation by over a factor of 3, as quantified in the following subsections.

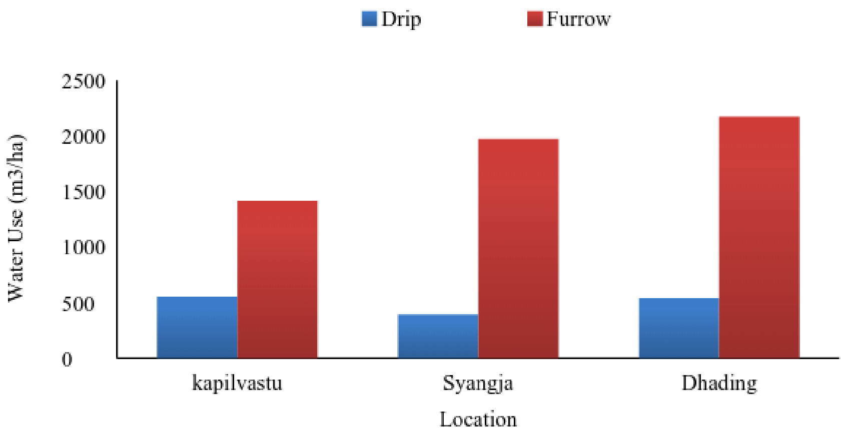

Figure 6. Water use efficiency at the field locations in Nepal over the 2013–2014 growing seasons.

3.3.1. Combined Forage Dry Matter Yield

Yields of forage were significantly influenced by irrigation system (Figure 7). Total dry matter yield under drip irrigation was 2447 kg/ha, 5411 kg/ha, and 4202 kg/ha for Kapilvastu, Syangja, and Dhading respectively. Similarly, total dry matter yield with furrow irrigation was 2066 kg/ha, 5003 kg/ha, and 4274 kg/ha for Kapilvastu, Syangja, and Dhading, respectively. Thus, total dry matter forage yield under drip irrigation system was greater compared to furrow irrigation system at two of the three sites.

3.3.2. Yield and Irrigation Water Use Efficiency

In Kapilvastu, drip irrigation reduced water use by 61.0% and led to 15.5% more fodder production, whereas in Syangja water saved was 80.0% with yield advantage of 7.5%. In case of Dhading, water saved was 75.0% while yield was lower by 1.7%. Adding the three sites together, drip irrigation used 73% less water while yielding 7% more dry matter.

Dividing dry matter yield by water use, WUE was 4.42 kg/m^3 for drip irrigation compared to 1.45 kg/m^3 for furrow irrigation in Kapilvastu; 13.71 kg/m^3 for drip and 2.53 kg/m^3 for furrow irrigation in Syangja, and 7.74 kg/m^3 for drip and 1.97 kg/m^3 for furrow irrigation in Dhading (Figure 8). Summed across the three sites, WUE increased by a factor of 3.99 from furrow to drip irrigation. Note the lower WUE under the hotter conditions of the Kapilvastu site, compared to the other two sites.

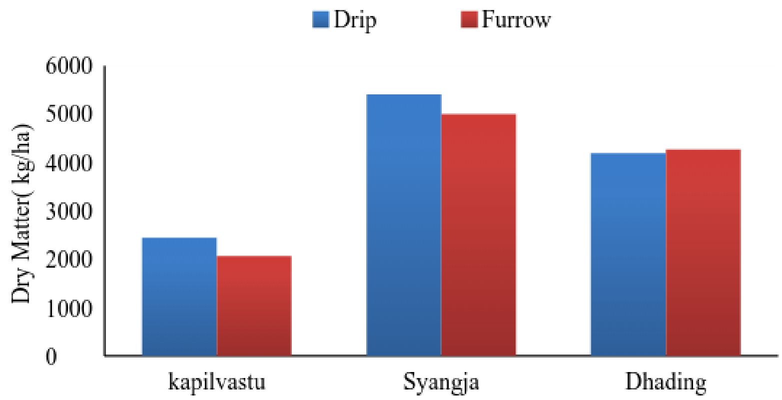

Figure 7. Dry matter production at the field locations under different irrigation systems in Nepal, combined over the 2013–2014 growing seasons.

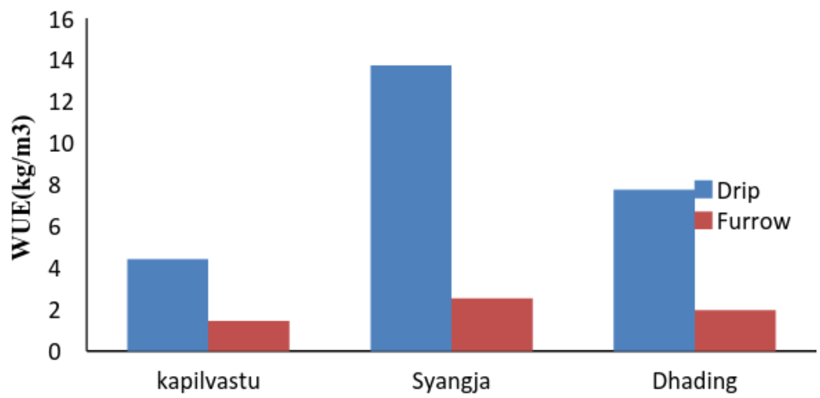

Figure 8. Water use efficiency in various locations, in Nepal combined over the 2013 and 2014 season.

The uniformity coefficient and distribution uniformity of randomly selected drip laterals were determined to test the performance of the drip irrigation system in all the locations. The measured uniformity coefficient in Kapilvastu, Syangja and Dhading was 76.80%, 83.43% and 60.25% respectively (Table 5). The distribution uniformity in Kapilvastu, Syangja, and Dhading was 88.79%, 89.23% and 91.32%, respectively. The application efficiency in Kapilvastu, Syangja and Dhading was 74.45%, 76.05% and 73.25%, respectively. These results suggest that the drip system was working satisfactorily and that the water was applied efficiently, without much loss.

Table 5. Uniformity coefficient (CU), distribution uniformity (DU) and application efficiency (AE) for drip irrigation at various sites, Nepal, 2013/2014 (percentages).

	Uniformity Coefficient (CU)	Distribution Uniformity (DU)	Application Efficiency (AE)
Kapilvastu	76.80	88.79	74.45
Syangja	83.43	89.23	76.05
Dhading	60.25	91.32	73.75

In summary, the drip irrigation system worked satisfactorily. Drip irrigation saved water and had similar or greater yield and much better WUE as compared to furrow irrigation. The drip irrigation method should allow growing fodder in more areas of Nepal and better utilization of limited water and land resources.

3.4. Soil Nutrients

3.4.1. Effect of Irrigation Type and Cropping Pattern on Soil Nitrogen

The effect of irrigation type on soil nitrogen was highly significant (Table 6). Drip irrigated plots had lower soil nitrogen (0.07%) than the furrow irrigated plots (0.08%). This may be due to better uptake of nitrogen by plants under the drip irrigation system, as application of water can increase nutrient availability and the transformation of nutrients or fertilizers in the soil [22]. Mineralization of organic nitrogen is proportional to soil water, which also influences nitrogen movement and uptake by plants [23]. The effect of fodder crop species on soil nitrogen was not significant (Table 6).

Table 6. Effect of location, irrigation method and cropping system on soil nutrients and on dry matter production.

Treatments	Total Nitrogen (%)	Available P_2O_5 (kgha^{-1})	Exchangeable K_2O (kgha^{-1})	DM Production (kgha^{-1})
Locations				
Kapilvastu	0.070 ^{c}	89.19 ^{b}	90.62 ^{c}	3009 ^{c}
Syangja	0.073 ^{b}	97.96 ^{a}	176.05 ^{a}	6942 ^{a}
Dhading	0.080 ^{a}	16.22 ^{c}	113.40 ^{b}	5651 ^{b}
LSD	0.00065 **	0.52 **	1.07 **	928 **
SEm±	0.0013	0.16	0.33	290
Irrigation Methods				
Furrow	0.08 ^{a}	67.58	126.27	5041
Drip	0.07 ^{b}	68.00	127.11	5360
LSD	0.00053	NS	NS	NS
SEm±	0.0011	0.13	0.27	580
Cropping system				
Cowpea	0.07	71.48 ^{a}	126.96	1951 ^{c}
Cowpea + Teosinte	0.07	66.05 ^{b}	126.73	6115 ^{b}
Teosinte	0.07	65.83 ^{b}	126.37	7535 ^{a}
LSD	NS	0.53 **	NS	1057 **
SEm±	0.0016	0.18	0.68	368
CV%	10.28%	1.36%	2.63%	24.72%
Grand mean	0.07	67.79	126.93	5200

Means in the same column followed by the same letter (a, b, or c) are not significantly different ($p > 0.05$). DM: dry matter. LSD: least significant difference. NS: Not significant. SEM: standard error of the mean. **: Significant at $p < 0.01$.

3.4.2. Effect of Irrigation Type and Cropping Pattern on Soil Available Phosphorus

There was significant variation from site to site in soil available phosphorus (Table 6). The highest soil available phosphorus (97.96 kgha^{-1}) was observed in Syangja, followed by 89.19 kgha^{-1} in Kapilvastu, and 16.22 kgha^{-1} in Dhading. These differences in soil available phosphorus were primarily due to the initial soil conditions. The effect of irrigation type on soil available phosphorus was not significant (Table 6), although the cropping pattern influenced the amount of soil available phosphorus. The highest level was for cowpea planted plots. Soil available phosphorus was lower and similar for the intercropped and teosinte cropped plots (Table 6).

Phosphorus is relatively immobile in soil. Mass diffusion is the major process controlling its movement. Soil moisture indirectly regulates soil phosphorus mobility [24]. The extractable soil P is highest at the soil surface, where the P fertilizer was applied. The level of P decreases from top soil layer to the subsoil level due to plant uptake in the top portions of the soil profile [25]. One study found that the Olsen P content throughout the 0–60 cm layer under drip or subsurface irrigation was lower than that under furrow irrigation [26]. However, the total, organic and inorganic P contents from 20 to 60 cm under drip irrigation were similar or higher than to those under furrow irrigation, but were lower under subsurface irrigation than under furrow irrigation [26].

3.4.3. Effect of Irrigation Type and Cropping Pattern on Soil Exchangeable Potassium

There was significant variation from site to site in residual soil exchangeable potassium (Table 6). The highest soil exchangeable potassium (176.05 $kgha^{-1}$) was observed in Syangja, followed by Dhading (113.40 $kgha^{-1}$) and Kapilvastu (90.62 $kgha^{-1}$). These differences in soil exchangeable potassium was again primarily due to the initial soil conditions. There was no effect ($p > 0.05$) of irrigation type or crop on soil exchangeable potassium.

Research suggests that injecting K through the sub-surface drip with the water can carry this nutrient to the soil surface as well as deeper into the profile [27]. Under these conditions, adequate K was available to the plant regardless of the application method (dry material broadcast over the top, or dissolved in water and injected through sub-surface drip). On the other hand, another study found a potential leaching risk for applied K under furrow irrigation, as compared to drip irrigation [28].

4. Conclusions

Agriculture must meet future food security challenges by increasing production while conserving important natural resources [29]. Freshwater is an increasingly limited resource that is often mismanaged. Efforts to improve water use management and efficiencies for crop growth need to be a high priority for farmers. In Nepal, 70% of the population works in the agriculture sector. Although water is one of the most abundant natural resources in the region, Nepali farmers face water scarcity and water-related hazards as they experience unpredictable rainfall patterns, long dry seasons, and increased frequency of extreme floods. Rapid melting of glaciers in the Himalayas has also reduced the amount of freshwater available to farmers from streams. Our efforts in the present research program tested new tools and systems to increase water security and efficiency that could be readily adapted by smallholder farmers. The primary finding of the research is that drip irrigation yielded similar dry forage biomass as compared to the traditional furrow irrigation method, while drastically reducing water use. Interestingly, intercropping did not yield more compared to single cropping, although intercropping can have other important agronomic values. The improved WUE of drip irrigation could allow sustainable expansion of irrigated area and cost-effective provision of adequate fodder for livestock systems in water-limited districts of Nepal.

The lack of effective irrigation systems is a major impediment to agricultural productivity in Nepal. Although currently the dominant irrigation methods used are basin/border irrigation for cereal crops and furrow irrigation for fodder crops, drip irrigation is a technology that can significantly improve WUE. Our findings indicate that the controlled and timely application of water through drip irrigation enhances fodder yields and especially WUE during the dry seasons, leading to more effective utilization and resource conservation of available land, fertilizer and water. Based on our field experience, drip irrigation is a relatively simple, low-input technology that can substantially expand the ability of smallholder farmers to plant fodder and other crops during the dry season and increase resilience to fluctuating water supplies in a changing climate.

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