SOIL & CROP SCIENCES | RESEARCH ARTICLE

Determination of bed width on raised bed irrigation technique of wheat at Koga and Rib Irrigation Projects, North West, Ethiopia

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Determination of bed width on raised bed irrigation technique of wheat at Koga and Rib Irrigation Projects, North West, Ethiopia

Dires Tewabe1*, Atakltie Abebe1, Alebachew Enyew1 and Amare Tsige1

Abstract: Field experiments were conducted to determine the optimal range of bed width under the bed and furrow irrigation technique of wheat at Koga (clay soil) and Rib (loam soil) irrigation scheme, North West Amhara, Ethiopia during 2016/17 and 17/18 irrigation seasons. The experiment was arranged in a randomized complete block design having seven treatments of (40, 60, 80, 100, 120, 140 and 160 cm) bed width and the recommended water depth for each treatment and each site were measured and applied through Parshall flume. It was found that bed width on a raised bed in different soil texture had significantly affected yield and water productivity of wheat. The result indicated that 60 cm to 80 cm bed width at Koga showed up to 26% yield advantage and saves about 25% irrigation water as compared to farmer practice. Similarly, Plant height has statically difference with farmer practice but the panicle length of wheat has no significant difference between the normal irrigation practice and the optimal bed width. Moreover, using 100 cm to 140 cm bed width at Rib (loamy soil) has up to 27% yield advantage and

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PUBLIC INTEREST STATEMENT

Water scarcity and irrigation methods are the major factors that limit the productivity of the crop in irrigation. Researchers found that raised bed irrigation improves yield and water productivity of wheat. However, in the Blue Nile Basin, Ethiopia, farmers cultivate wheat using flat panting methods through flood, border and furrow irrigation techniques which results in farmers lose up to 50% water through deep percolation and tail water loss and causes water shortage at the basin. In addition cultivation of wheat on flatbed endangers the crop by excess irrigation, poor aeration, and leaching of nutrient availability to the crops. Bed and furrow method is the planting of wheat on the bed which consumed less water and gave high grain yield as compared to flat border irrigation method. So, with optimum raised bed irrigation techniques, farmers can improve their wheat yield, water productivity and proper land utilization in the study area.
saves 28% irrigation water as compared to farmer practice. The plant height showed a statically significant difference but the panicle length of wheat has no significant difference between the farmer irrigation practice and the optimum bed width. Therefore, we concluded that the cultivation method under different soil texture and raised bed width affect yield and water productivity of wheat.

Subjects: Agriculture & Environmental Sciences; Agriculture and Food; Soil Sciences; Agronomy; Environment & Resources; Conservation – Environment Studies

Keywords: Bed width; wheat; Koga; Rib

1. Introduction

Ethiopia is endowed with a substantial amount of water resources but very high hydrological variability. Many perennial and annual rivers exist in the country. Quite a significant number of lakes, dams, and reservoirs are also found in various parts of Ethiopia. Based upon the various river basin master plans and land and water resources survey, the aggregate irrigation potentials of Ethiopia have been estimated to be 2.6 million ha net and the gross irrigation potential would be about 3.7 million hectares (Aquastat, 2011). The On-farm Water Management Project during the last three-decade has improved the water availability at the farm by minimizing conveyance losses. The present situation of acute shortage of irrigation water and problems in many parts of the country has further emphasized the need to utilize the available canal water more efficiently. It is important to note that inefficient irrigation is the major cause of salinity and shallow water table in most of the irrigation projects of the world (English, James, & Chen, 1990).

Farmers use surface irrigation systems to irrigate wheat through furrow, border strip and basin technique due to those systems being low in cost, easier to the farmers to construct, operate and maintain. But the efficiency of surface irrigation, however, is lower and in some cases, farmers may lose up to 50% water delivery in deep percolation and runoff (Tadesse, Solh, Braun, Oweis, & Baum, 2016). This method is the most common technique being practiced throughout the world, implying that water distribution is uncontrolled and inefficient (Bilibio, Carvalho, Hensel, & Richter, 2011). When water demand is increasing in irrigated agriculture, the need to increase water productivity/water use efficiency is crucial. Therefore, it required prior consideration for implementing water management practices. Generally, the wheat crop is sown on flat, which often endangers the crop by excess irrigation. In the bed and furrow irrigation systems, the plants are grown on raised beds which not only use irrigation water more efficiently but also ensure better crop growth under heavy rains (Berkout, Yasmeen, Mąssood, & Kalwij, 1997).

Conventional flat planting and flood irrigation are commonly used for growing wheat production. This leads to ineffective use of applied nitrogen, poor aeration and leaching, crop lodging, lower water use efficiency, and crusting of the soil surface (Majeed et al., 2015). On the other hand, the bed planting system improves the method of weed control, facilitates mechanical cultivation during the crop growing season and improves the stands of the plants (Miah, Hossain, Duxbury, & Lauren, 2015). It also provides an opportunity for easy field entry resulting from row orientation on the beds, and irrigation water management is more efficient, less labor required with the use of furrows than conventional flood irrigation (Fischer, Sayre, & Ortiz Monasterio, 2005; Sayre & Moreno Ramos, 1997). Raised bed irrigation method permits more efficient use of irrigation water as compared to the basin or border irrigation (Hassan, Hussain, & Akbar, 2005). Bed and furrow irrigation in wheat production, save more than 30-35% of irrigation water, 13.4% higher grain yield than flat border irrigation method (M. Ahmad, Ghafoor, Asif, & Farid, 2010; Hussain et al., 2018). A study in Egypt also showed that the application of raised-bed techniques in farmers’ irrigated fields results in 25% saving in irrigation water, 30% increase in wheat yield and 74% improvement in water use efficiency (Swelam, 2016). Similarly, the average irrigation duration decreased by 35.6% in the case of bed and furrow irrigation method (R. Ahmad & Mahmood, 2005;
Hassan et al., 2005) and improves 15% higher fertilizer use efficiency (Majeed et al., 2015). Kalwij, Mirza, Amin, and Hameed (1999) reported that 30.6 % decrease in time spent on irrigation water applications in bed and furrow irrigation method for cotton production. In addition, the higher amount of uptake of nutrients under furrow irrigated raised bed planting techniques and irrigation schedules are associated with higher bio-mass accumulation which led to a higher amount of uptake of nutrients. The higher nutrient uptake with furrow irrigated raised beds is mainly due to less leaching loss of nutrients and availability of sufficient moisture for mineralization of native as well as applied nutrients (Idnani & Kumar, 2013).

The spacing between furrows depends on the water movement in the soil, soil texture, crop agronomic requirements as well as on the type of equipment used in the construction of furrows (Eba, 2018). When water is applied to a furrow, it moves vertically under the influence of gravity and laterally by capillarity. Clay soils have more lateral movement of water than sandy soils which favors capillary action (Watson et al., 1995). In Ethiopia, wheat is the most dominantly cultivated cereal crops under irrigation in the Koga irrigation command area while at Rib is the newly introduced cereal crops by farmers. In the traditional system of wheat cultivation, farmers are totally dependent on their traditional know-how and on the tools and resources available, they use flood irrigation as well as furrow irrigation. This method of irrigation technique causes farmers to irrigate excess water resources for wheat production, results in a water shortage problem in the study area. However, furrow and bed irrigation water management practices are not done and evaluated yet in the scheme for the major irrigated cereal crops like wheat. This study has evaluated the effect of furrow and bed irrigation practice and the appropriate bed width of wheat to improve the water productivity in the scheme.

2. Material and methods

2.1. Description of the study area
The experiment was conducted in a region where wheat production was dominantly cultivated irrigation schemes at Koga and Rib, North West Amhara, Ethiopia, for a continuous two years of 2016/17 and 2017/18 irrigation season to study the effect of beds width on wheat grain yield and yield component under silt clay and clay loam soil condition.

Koga irrigation scheme is located in the Northwest of Ethiopia at Mecha district, 41 km to the West of Bahir Dar city and 543 km to the North of the capital city, Addis Ababa at $37^\circ 7'29.72"$ Easting and $11^\circ 20'57.85"$ Northing and at an altitude of 1953 m a.s.l. The average annual rainfall of the area is about 1118 mm. The mean maximum and minimum temperatures are 26.8 °C and 9.7 °C respectively. Rib irrigation site is located in Fogera district Northwest of Ethiopia, 60 kilometers to the East of Bahir Dar city and 644 km North of capital city, Addis Ababa at $37^\circ 25'25"$ to $37^\circ 58'$ Easting and $11^\circ 44'52"$ to $12^\circ 03'$ Northing and at an altitude of 1794 m a.s.l. It receives 1400 mm mean annual rainfall. The mean daily maximum and minimum temperature of the study area was 30°C and 11.5°C. The area is characterized as mild altitude agro-ecology.

2.2. Experimental setup
The treatment has consisted of a raised bed and furrow irrigation technique having seven treatments (Table 1) using different bed width and a furrow width of 40 cm for each was arranged in a randomized complete block design with three replications having 10 m length. The raised beds and furrows were made manually and the height of beds was 15 cm. The seed rate used for the experiment was 150 kg ha$^{-1}$ and the spacing from row-to-row was 20 cm applied by drilling for all treatments. All agronomic practices including weeding, pesticide, and insecticide were done equally for all treatments. In both locations, the recommended local variety of Tay which was released by Adet Agricultural Research Center was used. A fertilizer rate of 121.1 kg ha$^{-1}$ NPS at planting and 150.13 kg ha$^{-1}$ Urea (50.13 kg ha$^{-1}$ at planting and 100 kg ha$^{-1}$ at the tillering stage) were applied equally for all treatment as per agronomic recommendation (Ayana et al., 2016). The experimental trial was conducted in the dry season and the recommended depth of water was
applied by measuring through Parshall flume. Farmers practice uses two rows on a single bed uses more water. In addition more land is lost for irrigation water application purpose (more number of irrigation furrows required). Whereas in our experimental treatment 80 cm bed width (four rows) on a single bed can save the irrigation water applied and easy for agronomic management as shown in figure 1.

2.3. Data collection

The collected data during the experiment were yield, plant height, panicle length, and 1000-seed weight. The sample of grain yield was measured with sensitive balance after harvesting, drying, threshing, and weight in gram then converted into ton ha\(^{-1}\). The plant height and panicle length were measured by simply taking a representative random sample within the plot and measured by a meter. The data of 1000-seed weight were counted using the help of the seed counter and weighted in gram. In the study site, climate data were recorded daily when the experiment took place but no rainfall was recorded in both years since the study was conducted in the dry season and both sites are found in the zone of uni-modal rainfall characteristics.

2.4. Soil sampling and analysis

The soil sample was collected from both sites before the start of the experiment. A soil sample for each site and each year was taken from a depth of (0–20 cm) at the experimental site randomly, and well mixed independently to make a composite sample. Then the composite sample was well dried in air and sieved through 2 mm mesh to remove residues, stones and bad materials. The particle size of the sample was determined using the hydrometer method (Bouyoucos, 1962). The

| Treatment | Bed width | No of Rows | Treatment | Bed width | No of Rows |
|-----------|-----------|------------|-----------|-----------|------------|
| T1        | 40 cm     | 2          | T5        | 120 cm    | 6          |
| T2        | 60 cm     | 3          | T6        | 140 cm    | 7          |
| T3        | 80 cm     | 4          | T7        | 160 cm    | 8          |
| T4        | 100 cm    | 5          |           |           |            |

Figure 1. Farmers irrigation practice (A) and bed and furrow irrigation (B) (T3) at the site.

Table 1. Treatment setup of at different bed width
PH of the soil was analyzed by diluting the sample with water ratio of 1:2.5 and measured using glass electrode PH meter, total Nitrogen (N) was determined using Micro-Kjeldahl method (Horneck, Sullivan, Owen, & Hart, 2011), available phosphorus (P) was determined by Olsen methods (Olsen, Sommers, & Page, 1982) while the cation exchange capacity (CEC) was tasted using ammonium acetate method (Cottenie, 1980). The field capacity (FC), permanent wilting point (PWP) and available water (AW) were done at Adet Agricultural Research Center soil laboratory using the gravimetric method.

2.5. Data analysis
All the data on yield, yield parameters, and water productivity were analyzed for variance using the Statistical Analysis (SAS) software. Differences among treatment means were examined for statistical significance using the “Least significant difference (LSD) test” and “Duncan’s Multiple New Range Test (DMRT)” standard at 5% significance level. The water productivity of each treatment was calculated as the ratio of yield to the depth of applied water (Kijne, Barker, & Molden, 2003).

3. Results and discussion

3.1. Soil characteristics of the study site
The result of the soil sample analysis at Koga site shown that (Table 2) the soil textural classification lay under the clay soil texture according to (Hazelton & Murphy, 2016) and the other physical characteristics were also similar with (Abiyu & Alamirew, 2015). The soil analysis at Rib has shown that the soil is a light clay classification and has high alluvial deposited soil that comes from a mountainous area at the upstream of the Rib River. The analysis of the average bulk density of both sites indicates that the soil is suitable for crop root (Wale, Sebnie, Girmay, & Beza, 2019). The total available water was higher at Rib than at Koga this may come due to variation in soil textural classification.

The chemical properties of the soil analysis (Table 3) indicate that the PH-value of Koga is low according to (Agumas, Abewa, & Abebe, 2014) indicates that a strongly acidic problem due to high exchangeable acidity and high exchangeable Aluminum (Al³⁺), low available phosphorus (Clements & McGowen, 1994) and medium total nitrogen according to (S. R. Olsen, 1954). This strongly acidic problem may affect the potential yield production of wheat at the Koga scheme. While at Rib the cation exchange capacity (CEC) is high as classified by (Hazelton & Murphy, 2016), high available phosphorus content and medium total nitrogen. The high available phosphorus at Rib is may be due to high fertile soil deposition that comes from the upstream of the watershed.

| Site | FC (%) | PWP (%) | TAW (mm m⁻³) | Sand (%) | Silt (%) | Clay (%) | bulk density (g cm⁻³) |
|------|--------|---------|--------------|----------|----------|----------|----------------------|
| Koga | 30.8 ± 1.7 | 19.2 ± 1.2 | 135.2 ± 6.3 | 20.2 ± 3.8 | 22.4 ± 2.7 | 57.3 ± 2.5 | 1.21 ± 0.15 |
| Rib  | 59.0 ± 1.3 | 21.0 ± 1.4 | 143.0 ± 3.4 | 24.0 ± 2.4 | 36.0 ± 3.5 | 40.0 ± 3.2 | 1.24 ± 0.13 |

| Site | CEC (Cmol+ kg⁻¹) | N (%) | P (ppm) | PH-H₂O |
|------|-----------------|-------|--------|--------|
| Koga | 20.1 ± 2.7 | 0.12 ± 0.03 | 11.4 ± 2.7 | 5.13 ± 0.13 |
| Rib  | 33.0 ± 2.4 | 0.23 ± 0.05 | 32.3 ± 2.4 | 6.49 ± 0.34 |
3.2. Wheat grain yield

The study had conducted at silt clay soil (Koga) and loamy/alluvial deposited soil (Rib) to determine optimum bed width planted in mid-December under irrigation. The result shows that a significant difference between different bed widths on both sites and gave the highest grain yield of 2.85 ton ha\(^{-1}\) at silt clay soil using 80 cm bed width. On the other hand, in the alluvial deposited soil; the maximum grain yield of 4.99 ton ha\(^{-1}\) (Table 4) had obtained under 120 cm bed width. The production of wheat at Koga scheme was too low due to strong acidic problems in the scheme. The result reveals that lateral movement in the Rib irrigation scheme (loamy soil) was higher than the Koga (clay soil) irrigation scheme. The panicle length and thousand seed (TS) weight had not shown a significant difference while plant height had a significant difference between bed widths on both locations. The plant height was higher in narrow beds and shorter when bed width increases this is due to low lateral water movement in wider beds. Generally, the result displayed that the production of wheat under optimal raised bed width had 26 % yield advantage at Koga and 27 % at the Rib irrigation scheme as compared to farmer irrigation practice (treatment 1). This result is agreed with the finding of Soomro et al. (2017), they reported that wheat crop produced 24.65 % yield advantage and Razaq, Khan, Sarworf, and Mohammad Jamal (2019) found that 13.0 % higher grain yield under optimal raised-bed irrigation compared to the conventional irrigation system. Mollah, Bhuiya, and Kabir (2009) also reported that wheat planting using 70 cm wide beds with two and three plant rows had 21 and 20 % yield increment respectively over the conventional method. In addition, the wheat yield was about 16.6% higher with nearly 50% less irrigation water with layering precision land leveling and raised bed planting compared to traditional practices (Jat, Gupta, Saharawat, & Khosla, 2011). The obvious reason for higher yield production under optimal bed width is due to the effective utilization of land by reducing the number of furrows and a good lateral movement of the water.

### Table 4. Average of the two season wheat yield and yield component parameter

| Bed Width (cm) | Yield (ton ha\(^{-1}\)) | Plant height (cm) | Panicle length (cm) | TS Weight (g) |
|---------------|--------------------------|-------------------|---------------------|---------------|
|               | Koga | Rib | Koga | Rib | Koga | Rib | Koga | Rib | Koga | Rib |
| 40            | 2.26\(^{a}\)c | 3.93\(^{c}\) | 85.2\(^{a}\)b | 91.4\(^{b}\) | 8.6 | 9.1 | 34.0 | 30.5 |
| 60            | 2.67\(^{ab}\)c | 4.47\(^{b}\) | 89.1\(^{a}\) | 94.1\(^{ab}\) | 9.3 | 9.5 | 33.6 | 29.4 |
| 80            | 2.85\(^{a}\)c | 4.45\(^{b}\) | 86.6\(^{a}\)b | 97.3\(^{a}\) | 8.9 | 8.9 | 34.0 | 30.1 |
| 100           | 2.63\(^{ab}\)c | 4.54\(^{ab}\) | 87.7\(^{ab}\) | 94.6\(^{ab}\) | 8.5 | 9.0 | 34.0 | 29.7 |
| 120           | 2.54\(^b\) | 4.99\(^{b}\) | 83.4\(^{ab}\) | 94.3\(^{ab}\) | 8.5 | 9.3 | 34.3 | 30.1 |
| 140           | 2.53\(^{a}\)c | 4.64\(^{ab}\) | 79.5\(^{a}\) | 96.8\(^{ab}\) | 8.0 | 9.5 | 33.6 | 30.6 |
| 160           | 2.45\(^{a}\)c | 4.31\(^{ab}\) | 81.8\(^{ab}\) | 94.3\(^{ab}\) | 8.0 | 9.5 | 33.3 | 28.2 |
| CV            | 6.9 | 8.6 | 7.6 | 4.6 | 7.9 | 11.2 | 2.8 | 10.4 |
| LSD           | 0.23 | 0.45 | 7.6 | 5.47 | 2.1 | 1.21 | 0.53 | 1.60 |

Note: Means with different letters within the columns are significantly different, while values with the same letter and no labeled are not significantly different at (0.05) level of confidence.

3.3. Wheat water productivity

Wheat cultivation on raised bed enhanced water productivity, grain yield and yield components as compared to the traditional flat sowing method (Razaq et al., 2019). From our study, the result revealed that water productivity was significantly affected by soil characteristics (Table 5) and the width of the raised bed. The optimal raised bed width produced 25 % in clay soil (0.93 kg m\(^{-3}\)) and 27 % in loam soil (1.56 kg m\(^{-3}\)) higher water productivity as compared to farmer practice (treatment 1). This result indicates that loamy soils have good lateral movement than heavy clay soils, and which was a similar finding with the report of Razaq et al. (2019) in Pakistan. The area of furrows per hectare in the wider beds is lower than the narrow beds resulting in received a lower amount of irrigation water. The saving of irrigation water by bed planting of wheat ranged from...
Table 5. Average of the two season water productivity of wheat

| Bed Width (cm) | Site | 40 | 60  | 80  | 100 | 120 | 140 | 160 | CV  | LSD |
|----------------|------|----|-----|-----|-----|-----|-----|-----|-----|-----|
| Water productivity (kg m\(^{-3}\)) | Koga | 0.74\(^c\) | 0.87\(^{ab}\) | 0.93\(^a\) | 0.82\(^{ab}\) | 0.83\(^b\) | 0.84\(^b\) | 0.79\(^{bc}\) | 6.9 | 0.07 |
|                 | Rib  | 1.22\(^c\) | 1.40\(^b\) | 1.39\(^b\) | 1.41\(^b\) | 1.56\(^c\) | 1.45\(^b\) | 1.35\(^{bc}\) | 8.6 | 0.14 |
18%-50% as reported by scientists (Choudhary et al., 2015; Gupta et al., 2002). The evident reason for higher water productivity under optimal bed width is due to the effective utilization of land by reducing the number of furrows.

4. Conclusion
When water scarcity increases, it is vital to use irrigation water wisely. If the land is not the limiting natural resource, the saved water can be applied to the new land with much higher production. In the study areas, wheat was growing using surface irrigation and a series of furrows with narrow bed leads to poor production and waste of water. The optimal raised bed width of wheat at Koga (clay soil) was 60 cm to 80 cm bed width while at Rib (loam soil) was 100 cm to 140 cm bed width which gave 26 % and 27 % grain yield advantage respectively as compared to farmer irrigation practice. In addition, using the optimal bed width, the water productivity of wheat had increased by 25 % in clay soil and 28 % on loamy soil as compared to farmer irrigation practice. The lateral movement of water in loamy soil was higher than clay soil which results in a possibility of production of wheat in a wider bed at Rib irrigation scheme. Generally, the cultivation of wheat using optimal raised bed width enhanced water productivity, crop yield and its components as compared to the traditional flatbed sowing and a series of furrows with a narrow bed method.

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