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Effect of crop establishment methods and mulch levels of thatch grass (*Hyparrhenia hirta*) on finger millet (*Eleusine coracana l*) productivity under minimum tillage conditions in Zimbabwe

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ABSTRACT

A field trial was conducted during the 2020-21 rainy season at Midlands State University, Kwekwe campus, to test the effect of crop establishment methods and thatch grass (*Hyparrhenia hirta*) mulching levels on finger millet productivity. The ultimate goal was to determine the best combination between mulch quantity and crop establishment method that would yield the highest finger millet grain yield. The trial consisted of three establishment methods, namely broadcasting, transplanting, and dribbling into rows, and five mulch levels: 0 tons/ha, 3 tons/ha, 6 tons/ha, 9 tons/ha, and 12 tons/ha, laid out in a 3x5 factorial structure in a CRBD. The trial results showed that transplanted finger millet performed statistically lower than the other crop establishment methods for most growth and yield attributes that were evaluated. Finger millet directly seeded into rows gave a 45.14% higher grain yield compared to finger millet established by transplanting, while finger millet established by broadcasting yielded 32% more than transplanting. The better performance of the heavily mulched treatments could be attributed to the mulch producing more soil water conservation, which in turn led to better crop productivity than in treatments where less mulch was used. However, for the broadcasting treatment, heavy mulching resulted in lower grain yield due to reduced plant population, as germination of the tiny finger millet seeds was impeded by excess mulch in such plots. It can be recommended that without irrigation capabilities, finger millet establishment through transplanting is inadvisable because the transplanted crop may fail to fully recover from the detrimental effects of transplanting shock.

Contribution/Originality: The results found from this study contribute to the advancement of knowledge on the use of thatch grass, (*Hyparrhenia hirta*), at different application quantities/ha, as a suitable mulching substance in the production of finger millet in Zimbabwe. It also examines the interaction between finger millet establishment methods and mulch levels, an area that has not been extensively researched and published on in Zimbabwe and abroad.

1. INTRODUCTION

Finger millet is a neglected crop whose production is currently on the decline, but it remains an important climate-resilient food crop that has the potential to offer income, food, and nutritional security to most subsistence farmers scattered around drought-prone regions of Zimbabwe. Sagar et al. [1] stated that finger millet is regarded as a low fertilizer and moisture input crop for the smallholder farming sector; however, under such low input conditions, the crop also produces poor yields. According to Mbanyele et al. [2], growing small grains like finger millet in the poor soils of drought-prone environments of Africa and Asia is not only important for food and nutritional security but also for the provision of raw materials that can be used in the manufacturing of stock feeds and beverages, starting at the household level. It is against this background that many developing countries in the world, and in particular Africa south of the Sahara, are adopting the production of these traditional small grains. Since finger millet is drought-tolerant, has multiple uses, and can thrive in less fertile soils, its adoption by farmers perfectly fits within the climate change resilience-building cropping strategy.

Hamba et al. [3] stated that the current productivity of finger millet in farmers' fields is low, and they attributed this low productivity to the poor adoption of improved varieties and other agronomic production techniques by farmers. Kimudu et al. [4] argued that, besides varietal selection, methods of sowing or crop establishment are also important agronomic factors affecting the productivity of finger millet. Proper sowing methods are important non-monetary inputs in finger millet production, which greatly affect its growth, yield, and quality. Besides transplanting, another prominent establishment method of finger millet is direct seeding into the soil. This direct seeding can be done either by broadcasting or drilling into rows. Directly seeded finger millet (DSFM) as an establishment method can play a key role in increasing finger millet production because it is a faster and easier way of sowing, which ensures that optimum plant population is attained in a less labor-intensive way [5]. Finger millet is a very small-seeded crop with 400 seeds/g, thereby making its establishment by dribbling into rows ideal, at a seeding rate of 10kg/ha. An interrow spacing of 40 cm and an in-row spacing of 10 cm is also considered ideal for finger millet. According to Liyanage et al. [6], farmers in the Southern dry zone of Sri Lanka are cultivating finger millet mostly under rainfed conditions, and the majority of them practice random broadcasting as a crop establishment method. These farmers generally continue to get considerably lower yields at the end of the season. Yayeh and Asargew [7] reported increased grain yields when finger millet was sown at an interrow spacing of 30 cm, as compared to the closer spacing of random broadcasting. They also noted that sowing seeds in rows is a good practice for rainfed finger millet cultivation because it leads to good yield and its labor requirements are less than transplanting. However, Liyanage et al. [6] found their variety 'Rawana' producing better grain yield than other finger millet varieties they tested when broadcasting seeds was adopted as the crop establishment method.

In Zimbabwe, farmers establish finger millet by transplanting seedlings either into rows or randomly in rainfed fields. In most cases, the transplanting method often leads to a lesser plant population due to the death of some transplanted plants after failing to overcome transplanting shock, consequently resulting in a remarkable decline in the yield of the transplanted finger millet crop. One major advantage of transplanting finger millet is that it can make use of excess plants that would be destined for discarding from thinning exercises.

Upon establishment, Finger millet plants immediately struggle with soil moisture shortages under rain-fed conditions due to the prevailing adverse climate change being experienced globally. In order to mitigate soil moisture shortages, soil moisture conservation approaches like mulching must be adopted. According to Kader et al. [8], mulching is a water conservation practice used in arid cultivated fields to preserve soil moisture, control temperature, and minimize soil evaporation rates. In cases where organic mulches are used, by the end of the season, the mulches will begin to decompose, thereby enhancing soil organic matter and boosting soil biological flora.

In conservation agriculture, generally, mulching is desirable because it conserves soil moisture, enhances the nutrient status of the soil, controls erosion losses, and suppresses weeds. Iqbal et al. [9]. Kodzwa et al. [10] mentioned that mulching, crop rotation, and reduced tillage are key conservation agriculture strategies that can be adopted, at least individually or in combination, to bring about a tremendous increase in crop productivity.

The mulching technique adopted in this research, therefore stands out as simple technology that small holder farmers can readily adopt within the frame work of climate proof cropping systems to alleviate soil moisture deficiencies According to Ye et al. [11] mulches bring about soil moisture conversation through their ability to control surface evaporation by reducing water exchange between the atmosphere and the soil surface.

Rahmani et al. [12] stated that all field mulching materials can be divided into three broad categories: organic, inorganic, and living mulches. Organic mulches are obtained from organic products, such as crop waste (straw and rice husks), waste from the timber industry (sawdust and bark), and green waste (leaves and wood chips), while inorganic mulches include gravel, film, bricks, and cobblestones made of polyethylene. Materials like clover, manila grass, dwarf lily turf, ryegrass, and other kinds of grasses that will be actively growing in the soil constitute the living mulches category. Wang et al. [13] discussed the advantages and disadvantages of using organic mulches in the form of crop/plant residues. They pointed out that in some cases, crop residues may harbor overwintering plant pests and diseases; therefore, those pests and diseases can easily spread from the mulch to the crop if the crop is susceptible to them. However, Iqbal et al. [9] observed that on the positive side, the use of dead plant residues as mulches has more benefits over the use of cover crops as mulches because cover crops may end up being resource competitors to the main crop of interest.

Mulching larger fields must be achieved easily by using crop residues; however, in Zimbabwe, the dilemma is that most of the crop residue will be in demand elsewhere on the farm [10]. Mainly, the crop residues are collected and stored securely for later use as supplementary livestock feed during the dry season. The crop residues can also be added to cattle kraals as bedding, so that upon their decomposition, the output of cattle manure on the farm increases.

Fortunately, mulching finger millet fields using thatch grass is a relatively safe technique since thatch grass does not harbor pests and diseases that are of economic importance to finger millet. Hyparrhenia grass is sustainably abundant in the savanna grasslands of Zimbabwe and has fewer competing uses. While some species of this grass are mainly used in thatching, some species are not suitable for thatching and have little grazing value. Hyparrhenia grass usually remains in the ecosystem in thick undisturbed stretches, which pose a serious environmental danger due to their susceptibility to veld fire during the dry season. Therefore, the practice of cutting excess Hyparrhenia grass and using it as mulch in finger millet fields can serve a dual purpose: one of being a veld fire mitigation measure and the other of being a drought mitigation strategy for finger millet; hence, it should be promoted.

Information on mulching quantities that are required by finger millet to achieve optimum yields is currently very limited, with no previous research having been done in that area. A review on mulching practices by Demo and Asefa Bogale [14] pointed out that conservation agriculture recommends that a minimum of 30% residue cover should be left on the soil surface. In circumstances where leaving more than 30% mulch cover is achievable, this general recommendation of conservation agriculture, of leaving at least 30% mulch cover, makes the actual potential of leaving residue cover (mulches) of more than 30% unknown. This makes it imperative to evaluate the actual potential of thicker mulch intensities of hyperrnia grass, which is abundant in Zimbabwe. Therefore, this current regime of moisture shortages, unknown mulch quantities to apply, and largely unstandardized crop establishment methods justify the need to test the effect of different finger millet establishment methods and mulching levels on finger millet productivity, so that farmers can adopt the best production strategy.

2. MATERIALS AND METHODS

Field experiments were carried out at Midlands State University, Kwekwe Campus, during the December 2020 to April 2021 cropping season. The site has loamy soils with the following soil parameters.

Table 1 presents the soil nutrition status at the research site.

Table 1. Soil status at the research site.

Parameter	Level measured	Status
Organic carbon	(0.37%)	Low
Available N	(48 kg/ha)	Low
Available P	(22.7kg/ha)	Low
Available K	(19 kg/ha)	Low
pH	(5.7)	Acidic

The experiment was conducted as a 3X5 factorial treatment in a Completely Randomized Block Design (CRBD) with 3 replications. The treatments consisted of 3 establishment methods, viz., direct seeding by drilling into marked rows, direct seeding by broadcasting and transplanting into rows 3 weeks after emergency [15]. With regard to mulches the experiment had 5 mulching levels, viz., 0% / no mulch (control), 3 tons/ha, 6 tons/ha, 9 tons/ha and 12 tons/ha. A Zimbabwean local landrace Finger millet variety called 'FMV1' was used as the test variety. Direct seeding into the soil of finger millet, both as drilling into rows and broadcasting was done on the 1st on December 2020, using a rate of 15kg seed per hectare. Transplanting of finger millet was done on 22nd of December 2020, manually by hand, where seedlings were uprooted and transplanted as 2 seedlings per station at 4cm deep into moist soil, [Sakadzo et al, 2019.[15]. For the non-broadcasting treatment, the ultimate Spacing of 40 cm inter row and x 10 cm in-row was adopted [16]. The weeds were managed by spraying a combination of herbicides [17], in particular, Metazachlor 1.5 Litres/ha + Atrazine 3 -5 Litres/ha pre-emergent herbicides. The recommended dose of fertilizer was a Nitrogen (N), Phosphorus (P) and Potassium (K) (NPK) ratio of 20:30:30 kg ha-1 applied as basal at sowing [18]. The weeds that later emerged were removed by hand pulling, as the experiment progressed. Harvesting of finger millet was done on 25 April 2021.

2.1. Data Collection

The researcher collected data on plant height, number of tillers at 12 Weeks After Sowing by sampling 3 plants per replication [19]. Total grain yield, 1000 seed weight, leaf area index and chlorophyll content were also collected and recorded by the researcher.

1. Plant height

Data on plant height was taken from 3 randomly selected plants in the net plots comprising the 3 middlemost rows and measured using a meter ruler at 84 Days After Sowing (DAS). At this point, no more increase in plant height was happening; the plants were at the grain-filling stage. Measurements were taken from ground level up to the plant tip.

2. Number of tillers

The number of tillers per plant was also evaluated by randomly selecting 3 plants from the 3 middle most rows at 84 Days After Sowing. Thinning to the required plant population had previously been done to the broadcasted and row-drilled plots at 30 days after planting. At 60 days after planting the plant was at the booting stage and no more tiller initiation was anticipated. Finger millet crop that was established by direct seeding to rows or transplanting into rows were later thinned to one plant per stand/hill spaced 40 cm x 10 cm, three Weeks After Sowing (WAS), Garjila et al, 2019 [19].

Leaf chlorophyll content. Leaf chlorophyll was estimated using the SPAD 502 Chlorophyll meter.

3. Leaf Area Index (LAI) Leaf-area index (LAI) per plot was measured using a LICOR- BIOSCIENCES 2200 canopy analyzer. Leaf Area Index (LAI) is described as the ratio of the areas (m2) of single-sided green leaves in relation to the to surface area (m2) of the ground on which those plants will be growing. It estimates the amount of leaf area in a plot and is a critical element of photosynthesis, evapotranspiration and leaf shading. LAI is hard to assess due to its spatial (horizontal and vertical) and temporal instability. If the canopy proves to be rapidly expanding, it will be a sign that a higher LAI will be obtained and the crop will be experiencing less stress, whilst if there is no rapid canopy expansion, it means the crop is under stress. According to Tanko and Hassan [20], LAI gives an indication on crop growth efficiency of most crops and is also useful in the analysis of canopy architecture, for estimation of important parameters like light interception, radiation use efficiency, plant growth, etc.

Grain yield and grain test weight. Grain yield and grain test weight were determined after grain cleaning at the end of the study. Finger millet heads were harvested separately from the three middle rows, which formed the net plot for all the treatments, to obtain the actual yield per treatment. Threshing and winnowing, to clean the grain, were done before the grain was weighed using an electronic scale. Average yield in tons/ha was obtained by converting the area of the plot to a straight fraction of a hectare before statistical analysis was performed. The 1000 seed count was obtained by the QAQC lab vacuum seed counter before weighing on a sensitive balance.

2.2. Statistical Data Analysis

Analysis of Variance (ANOVA) was done using GenStat 18.1, VNS, International Ltd. Means were subsequently separated using (LSD) least significance Difference at a 5% significance level.

3. RESULTS AND DISCUSSION (*VEGETATIVE GROWTH PARAMETERS*)

3.1. Results of Finger Millet Plant Height

Plant height results indicate that there was no significant interaction between crop establishment method and mulching levels ($p<0.05$). However, the main effects of plant establishment method and mulching levels significantly affected plant height ($p<0.05$). The transplanting method of crop establishment turned out to be the worst, giving the least average height of 65.53 cm followed by broadcasting, which gave 80.8cm and lastly row seeding, which was the best at 90.47cm. Plant height was found to be significantly higher for finger millet that was directly seeded into rows than for the broadcasting and transplanting treatments. These results are depicted in Figure 1.

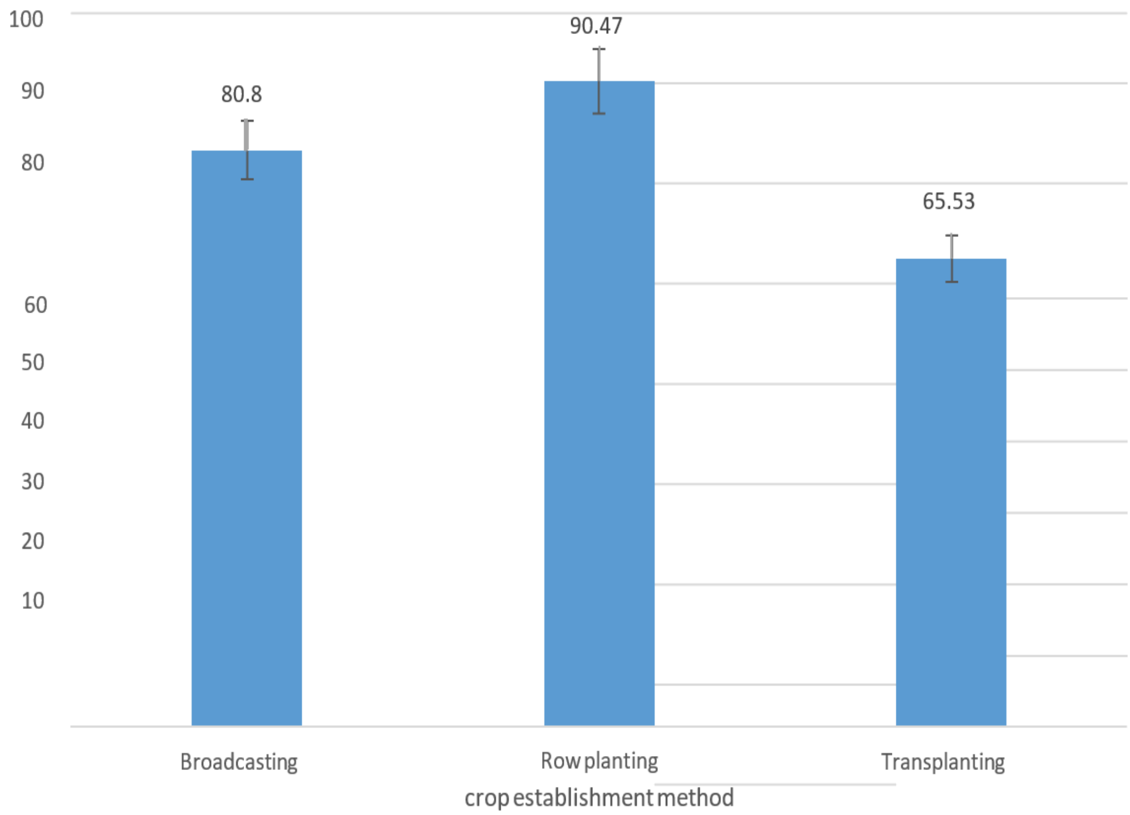

Figure 1. Presents the effect of crop establishment method on finger millet plant height in cm.

Plant height seemed to increase with an increase in mulching levels with the no mulch treatment giving an average of 62.78 cm which as the least whilst at 12 tons/ha mulch plant height was highest at 95.11cm which was the highest. However, at higher levels of mulch (between 9 and 12 tons/ha) the rate of increase in height was beginning to taper off as seen in Figure 2.

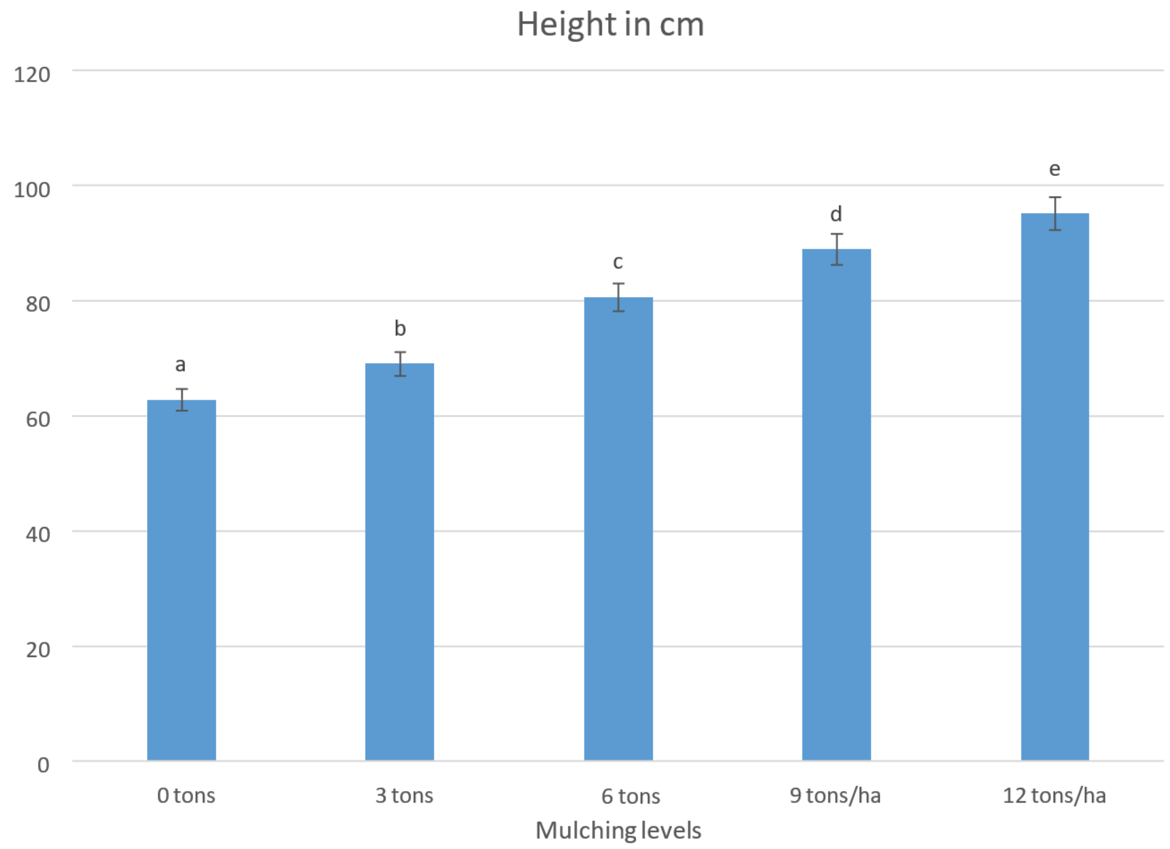

Figure 2. Presents the effect of mulching level on finger millet plant height.

3.2. Discussion on Plant Height

Mulching at higher amounts of thatch grass might have resulted in higher soil moisture conservation, which may have reduced water stress in the respective plots. This agrees with Kader et al. [8], who observed that mulching can help retain moisture in the root zone, allowing plants to receive water for extended periods.

Without water stress, the plants were able to have efficient physiological growth processes of cell division and cell elongation, which in turn produced a net effect of increased photosynthetic rates and vegetative growth, which ultimately translated to an increase in plant height. Lower height values for the broadcasted treatment, as compared to the row-dribbled treatment across all mulching levels, could be due to the fact that finger millet plants grown in rows were closer to each other in the row (10 cm apart) than in the inter-row (40 cm apart) as per the spacing that was adopted. Due to this serious plant proximity to each other, plants competed among themselves for space and sunlight, so they had to grow taller than those established by the direct broadcasting method, where the spatial arrangement from one plant to another had more space.

However, at 9 and 12 tons/ha mulch direct row planting and transplanting continued to show an increase in plant height but broadcasting method suddenly showed a drop in plant height. This drop in height mainly at 12 tons/ha much under broadcasting method could be a direct result of less competition between plants. It was observed that germination of finger millet was not complete and even in heavily mulched and broadcasted plots. Finger millet germinating seed was smothered by the thick mulches in the same manner weed seed germinating is smothered by thick mulches giving a slightly depressed plant population in such plots. The higher plant height in treatments with row planting is in conformity with the findings of Hebbal et al. [21] who found that plant density brings about plant morphological changes, such as increase in plant height due to competition between plants for light, moisture and nutrients. Lastly the transplanting method produced plants that were shorter than those that were directly established by either broadcasting or row dribbling. This could be a case of plants failing to overcome stress related to transplanting shock.

In general, height observations in this research suggest that, higher application rates of mulches were responsible for the differences in plant height and this might have been due to, mulches conserving moisture in the soil and mitigate the effects of drought stress. When soil moisture is not severely limiting, macro nutrients like Nitrogen, Phosphorus and Potassium present in the fertilizers that were applied were readily absorbed and utilized by finger millet. Nitrogen in particular is integral to the synthesis of proteins and other growth factors and Phosphorus in integral in root development which encourages efficient water and nutrient uptake. Similar findings were reported by Wafula et al. [22] in their experiment they conducted in western Kenya, where they observed that increased levels of phosphorus increased finger-millet height over non-fertilizer application or when fertilizer application was at lower rates.

3.3. Results on Effective Tillers Per Plant

Three plants per row, from the 3 innermost rows of every plot, were randomly selected for tiller evaluation. The analysis of variance indicated that there was a significant interaction ($P < 0.05$) between crop establishment method and mulching rates on the number of effective tillers. Tiller formation appeared to be encouraged by high mulch intensities under the broadcasting method of crop establishment. The highest number of effective tillers per plant, which was 2.379, was recorded at the 12 tons/ha level of mulch application under the broadcasting crop establishment method. The least number of tillers, 1.053, was obtained at 0 tons/ha mulch under the transplanting method of crop establishment. From 0 to 12 tons per ha mulch broadcast finger millet tillered better than row-transplanted finger millet. However, at 9 tons/ha mulch, row planting and broadcasting produced statistically equal numbers of tillers. There was also no meaningful tiller formation for finger millet established in rows at low levels of mulching of 0 to 3 tons/ha, resulting in statistically equal numbers of tillers for the transplanting and direct row planting crop establishment methods (Table 2).

Table 2. Effect of crop establishment method and mulching levels on finger millet tillering.

Mulching levels					
Est. method	**0 Tons/ha**	**3 Tons/ha**	**6 Tons/ha**	**9 Tons/ha**	**12 Tons/ha**
Broadcasting	1.363b	1.577d	2.010e	2.107e	2.379f
Row seeding	1.133a	1.153a	1.473c	1.813e	1.987e
Transplanting	1.053a	1.157a	1.253b	1.463c	1.640d
Grand mean	1.741				
Sig	<0.001				
LSD	0.176				
CV	6.7				

Note: Means with different letters are statistically different.

3.4. Discussion on Number of Effective Tillers per Plant

The higher number of effective tillers per plant in treatments that were heavily mulched is an indication of better utilization and uptake of edaphic resources, mainly water and nutrients, which then stimulated more photosynthesis that led to better tiller initiation and support. Better tillering of the broadcasted treatment, as compared to the row-planted treatment, could also be an indicator of spacing and plant spatial arrangement in the field that was distinct between these two treatments. Broadcasted plants had a low plant population at higher mulch treatment levels due to the thick mulches hindering the total emergence of all finger millet seedlings. These results agree with the findings of Debbarma et al. [23], who reported that wider spacing facilitates more absorption of light energy, water, and nutrients to produce a massive root system, resulting in a higher number of tillers per hill. Tillering is a technique in plants that tends to compensate for depressed plant populations when plants are grown at wider spacing. Therefore, finger millet in heavily mulched and broadcasting treatments had the room to tiller better than row-planted crops that already had a higher effective plant population regime.

There was also no meaningful tiller formation on row-established finger millet, resulting in a statistically equal number of tillers for the transplanting and direct row planting crop establishment methods at low levels of mulch intensity.

A depressed number of tillers in the transplanted treatment could be due to the effects of tiller mortality, which refers to the death or withering away and failure of a tiller after it has been formed to develop into a reproductive offshoot plant. Tiller mortality is likely to have been more pronounced in the transplanted treatment than in other crop establishment methods, resulting in a depressed number of effective tillers/m2 under transplanting. This tiller mortality could have been caused by the failure of the transplanted finger millet plants to support initiated tillers, as the plants were concentrating on battling transplanting shock. These results disagree with the findings of other researchers who reported that the transplanting method can significantly increase tillering. Pandey et al. [24] reported that the number of tillers per m2 was significantly higher in the transplanted crop due to the presence of more tillers per plant, and they attributed this to the fact that they transplanted their seedlings when they were still very young. This had the effect of preserving seedlings' potential to achieve good tillering and root growth, and they declared that tiller production is optimized by transplanting seedlings at younger ages compared to direct seeding. However, on the other hand, the finding by Pandey et al. [24] that wider spacing, preferably square planting, exerted less competitive pressure among plants in the field, so each plant got the advantages of adequate space, nutrients, and other growth resources resulting in healthy plant growth with more tiller formation, is in conformity with this research, where more tillering was observed in the broadcasted treatment that had less plant populations.

3.5. Results on Leaf Area Index (LAI)

The interaction between crop establishment method and mulching levels significantly affected LAI. It was observed that at 0-6 tons/ha mulch, broadcasting had more LAI values as compared to plots that were direct seeding into rows. The LAI obtained from the Transplanting method of crop establishment was trailing behind the other two methods at all levels of mulching (Table 3). However, at 9 tons/ha, mulch statistically equal values of Leaf Area Index of 1.517 and 1.540 were observed for broadcasting and direct seeding, respectively. At 12 tons/ha, it was observed that direct seeding into rows produced a Leaf Area Index of 1.83, which was now statistically higher than broadcasting and transplanting, which produced 1.53 and 0.987, respectively.

Table 3. Presents the effect of plant establishment method and mulching levels on finger millet LAI.

Mulching levels					
Est. method	**0 Tons/ha**	**3 Tons/ha**	**6 Tons/ha**	**9 Tons/ha**	**12 Tons/ha**
Broadcasting	0.860bc	0.903bc	1.133e	1.517 f	1.53f
Row seeding	0.807bc	0.863b	1.050e	1.540 f	1.83g
Transplanting	0.613a	0.627a	0.713ab	0.783b	0.987cd
Grand mean	1.053				
Sig	<0.001				
CV	7.2				
LSD	0.1272				

Discussion on LAI- The increase in LAI with an increase in mulching levels that was observed can be attributed to soil water availability. Soil water availability is a primary input required for the development of leaves and the overall biomass of most crops and this is bound to result in a significant effect on LAI. An increase in mulch levels prevented rapid soil water loss by evaporation. This enabled better uptake of water and nutrients that was channeled towards better development of the leaf resulting in the LICOR-BIOSCIENCES 2200 canopy analyzer being able to pick the differences in LAI among the treatments. The higher LAI in treatments with more mulches is in conformity with the findings of Hebbal et al. [21] who found that plant density brings on morphological changes such as an increase in plant height due to competition between plants for light, moisture and nutrients. More light interception resulted in increased dry matter and LAI production per unit area. The transplanted treatment suffered from transplant shock and produced depressed LAI. This result agrees with the finding of Shiva et al. [25] who reported higher values in finger millet parameters of plant height (79.73 cm), leaf area Index (2.73), and total dry matter in 15-day-old seedlings of finger millet. They also attributed the higher growth parameters to reduced transplanting shock and better establishment of the seedlings.

3.6. Chlorophyll Content

For chlorophyll content, it was observed that the interaction effects between crop establishment method and mulch intensity was not significant ($p>0.05$). Similarly crop establishment method main effects were not significant ($p>0.05$). However, mulching intensity had a significant effect on chlorophyll content ($p<0.05$). The highest SPAD chlorophyll content reading of 58.1 was obtained at 12 tons/ha much intensity and the lowest chlorophyll of 27.6 was obtained at 0 mulch, respectively in a relatively linear form (Figure 3).

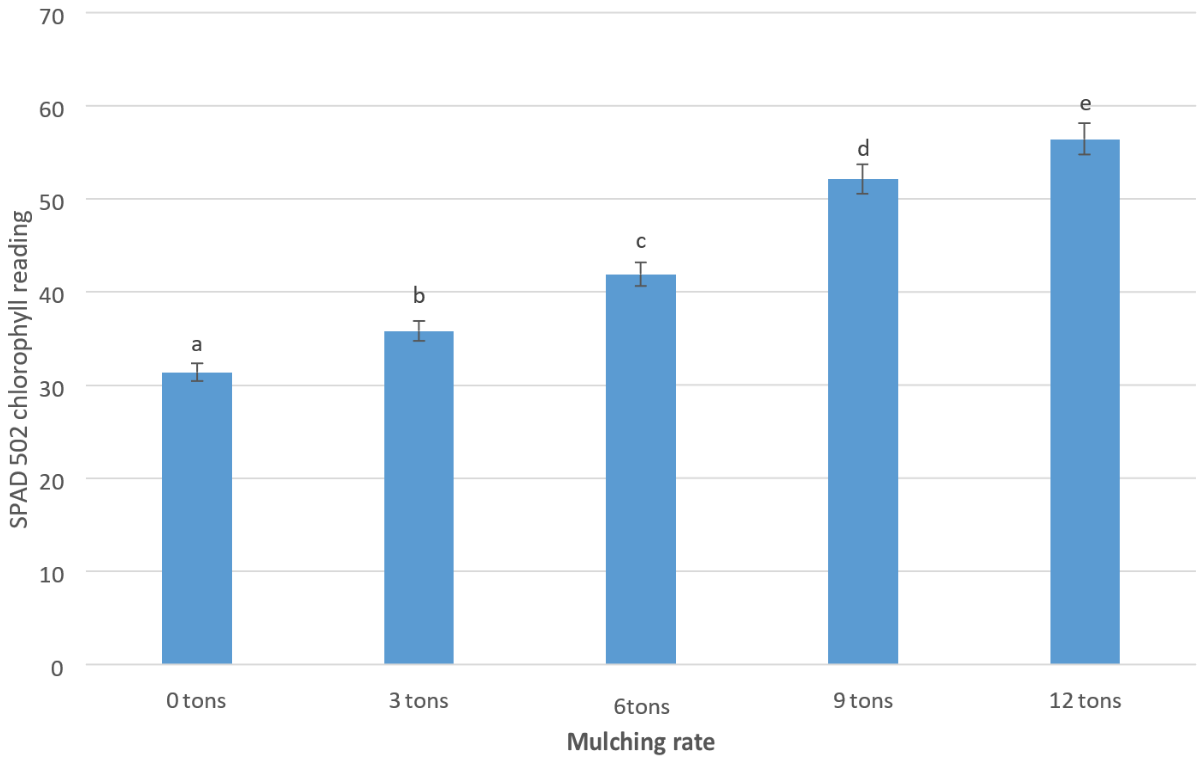

Figure 3. Depicts the effect of mulching level on finger millet chlorophyll content.

3.7. Discussion on Chlorophyll Dynamics

It may also be deduced that the positive correlation between increased mulch intensity and chlorophyll content can be attributed to improved water availability in the soil. The better the moisture conservation at higher mulch intensities, enabled stronger the differential Nitrogen absorption from the soil. Plant roots absorb soil nutrients like nitrogen and phosphorus more efficiently when soil moisture is not limiting. The more nutrients that were absorbed by the roots was partitioned to leaves and converted to chlorophyll synthesis. These results on chlorophyll content of this study presented above showed a positive correlation of chlorophyll content (represented by higher SPAD Values) to increased mulch intensity on measured plants, agree with Gangwar et al. [26] and who reported that the presence of more chlorophyll have a positive and significant effect on grain yield in rice.

3.8. 1000 Seed Weight Results

It was observed that only the crop establishment method and mulching levels main effects had a significant effect on grain test weight, while interaction amongst these factors was not significant. Crop establishment methods significantly affected 1000 seed weight with transplanting giving the least weight of 3.309g, followed by row planting, which gave 3.506g and lastly followed by broadcasting, which gave the highest grain test weight values of 3.611g as depicted in Figure 4.

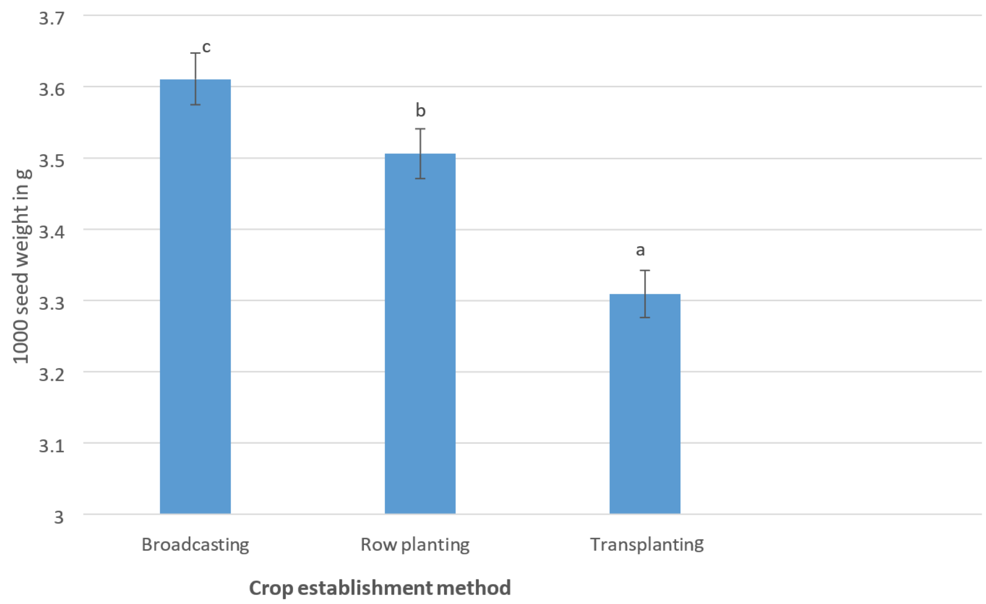

Figure 4. Depicts the effect of crop establishment method on 1000-seed weight of finger millet.

Grain test-weight on the other hand, showed a trend of increasing with an increase in mulching levels at all levels throughout. The least test weight of 3.043g was obtained at 0 mulch, whilst the highest test weight of 3.85g was obtained at 12 tons/ha mulch. However, the rate of increase in grain test weight between 9 and 12 tons/ha mulch, although significant, was tapering off (Figure 5).

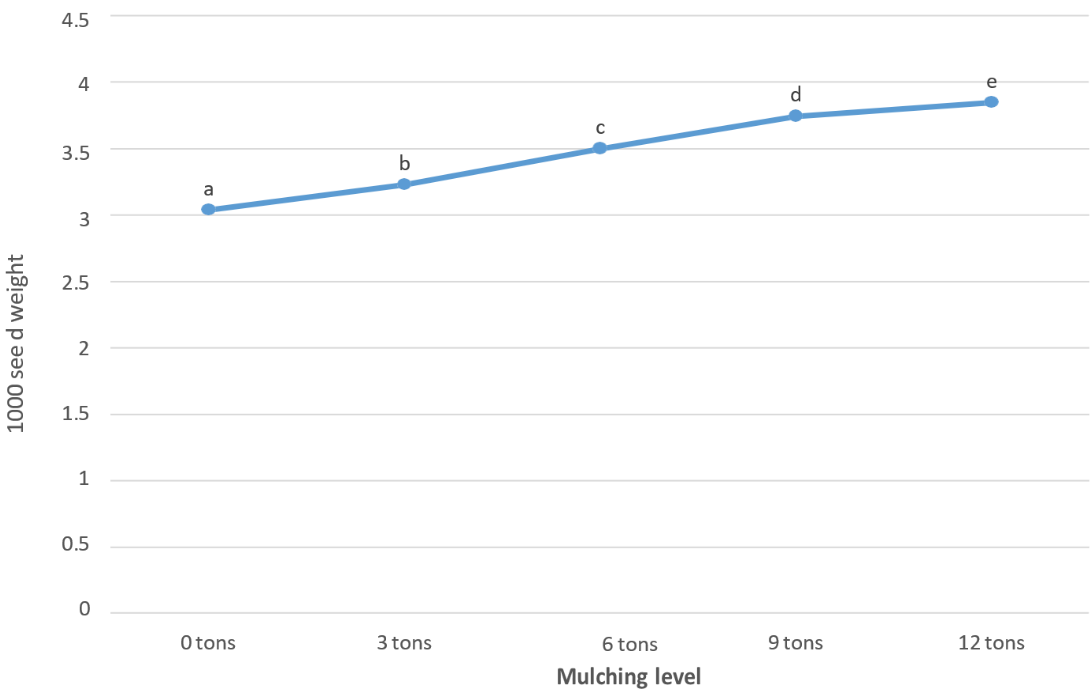

Figure 5. Effect of mulching levels on 1000-seed weight of finger millet.

3.9. Discussion on 1000 Seed Weight

Test weight, as represented by 1000 seed weight, is a function of various production factors that give an indication of grain development and filling patterns as influenced by various factors. This result of increased grain test weight with increased mulch levels is likely to result from better moisture conservation enhancement in plots that were heavily mulched than in plots that were scantily mulched. The conserved moisture was then absorbed by the plants and used for more photosynthesis and to support assimilate partitioning towards the grain. The more soil moisture that was available to the plants in the various mulched treatments, the more the assimilates that were partitioned towards the grain, resulting in heavier grain being produced on the 12 tons/ha mulch, which probably had conserved the highest amount of soil water.

The failure of the thinly mulched treatments to produce higher values for finger millet grain 1000-seed weight, as observed in this study, is in line with Rawat and Chauhan [27], who found that another reason for lower yield in their trial could be depressed 1000-seed weight results, which in turn could have been caused by improper filling of seeds as a result of moisture stress.

3.10. Grain Yield Results

The interaction effects between crop establishment method and mulching rates hand a significant effect on grain yield ($p<0.05$). Transplanting of finger millet produced the least grain yields cross all mulching levels. The highest grain yield, 1767.7 tons/ha, was obtained under row planting mulched heavily at 12 tons per hectare, while the least grain yield of 450.3 tons/ha was obtained when transplanting was done to unmulched plots. Direct seeding to either rows or broadcasting produced similar yields from 0- 6 tons per hectare of mulch. However, at higher mulch intensities of 9 and 12 tons/ha, direct row seeding outperformed direct broadcasting. At the highest level of mulching rate of 12 tons/ha it was observed that broadcasting produced diminishing grain yield. Transplanting and direct row planting had grain yield results that increased directly as mulching intensity increased across all mulching levels Figure 6.

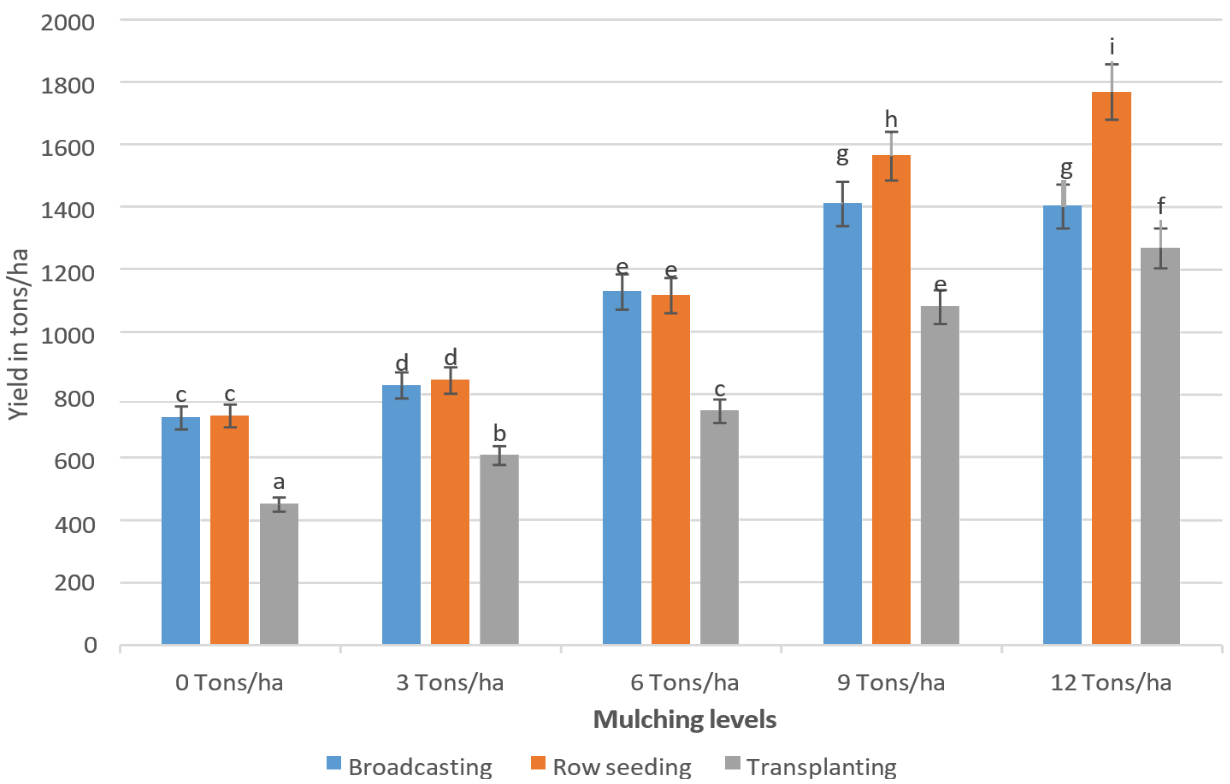

Figure 6. Depicts the interaction effects between crop establishment method and mulching level of finger millet grain yield.

3.12. Discussion on Finger Millet Grain Yield

Grain yield is a function of growth and yield-attributing parameters. Final grain yield is the main parameter for judging the comparative efficacy of the different mulching rates and plant establishment combinations on finger millet productivity. The poor performance of direct broadcasting at higher mulch intensities regarding grain yield is likely to have been caused by depressed plant populations in those broadcast plots. The depressed plant population that was observed in such plots was a result of the thicker mulches preventing even seed germination. Since the finger millet seed is small, its germination was easily smothered by the thicker mulches in the same manner as weeds' seeds are smothered by thicker mulch barriers, resulting in depressed plant populations. Since the crop establishment method and the mulches interacted to give varied plant populations in the various treatment plots, the results are in agreement with Korir et al. [16], who found that although wider spacing encouraged more tillers compared to the closer spacing, the closer spacing accommodates more plants per unit area, leading to significantly higher grain yield for the closer spacing compared to the wider spacing. They Korir et al. [16] then concluded that, though wider spacing encouraged growth through stem and leaf elongation and tiller formation, in terms of grain yields, this did not adequately compensate for the higher number of heads associated with the closer spacing, and thus a closer spacing achieved more grain yields as observed when row planting that had higher plant density outperformed broadcasting/transplanting that had wider gaps between plants.

Higher grain yield with higher mulch intensity levels, especially under direct row planting, could have been obtained due to better moisture conservation of the mulches that enabled better plant growth, which led to better enhancement of yield determinants of finger millet. Also, increased water availability in the soil passively ensures the simultaneous absorption of both moisture and soil nutrients like nitrogen. The higher the nitrogen that was likely to have been absorbed in heavily mulched plots could have supported more finger millet photosynthesis rates and photosynthate partitioning to grain yield. These findings agree with the observation of Ashoka et al. [28], who stated that finger millet also exhibits substantial drought tolerance and has the ability to sustain grain filling even under moisture stress conditions. Ilyas et al. [29] explained that the root architecture of finger millet is longer and denser, and this contributes significantly to their ability to absorb nutrients and water even when they are in limited quantities in the soil. This makes millets particularly important in regions where water scarcity is a major concern. The ability of finger millet to produce grain across all the establishment methods and mulching levels is a positive finding, which makes millet cultivation under conservation agriculture environmentally sustainable for farmers in Zimbabwe, where access to agricultural inputs and irrigation is limited.

However, the results of this study disagree with Sakadzo et al. [15], who studied the effect of crop establishment methods on finger millet productivity in Zimbabwe and reported that the transplanting method outperformed drilling and broadcasting. Again, [6] working with the finger millet variety 'Rawana', found that transplanting is the best practice to enhance finger millet yield and also found that sowing seeds in rows is an equally good method that leads to good finger millet yield. However, this trial was conducted under minimum tillage and drought conditions; hence, transplanted crops turned out to be the worst, possibly because of severe transplanting shock, which could otherwise be avoided in seasons where rainfall distribution is more even.

4. CONCLUSION

From the results of this study, it can be concluded that different crop establishment methods and mulching levels that were tested do have a significant effect on plant height, LAI, tiller number, chlorophyll content, grain test weight, and grain yield of finger millet. Furthermore, grain yield turned out to be a function of tiller number, 1000 grain weight, LAI, and chlorophyll content.

4.1. Recommendations

The researchers recommend that farmers adopt the row planting method of crop establishment and a higher mulching level of 9-12 tons/ha in order to achieve higher finger millet grain yields. However, further research is recommended to establish the actual potential of transplanting as a crop establishment method under irrigation because the erratic rains experienced in the year of this study had a more adverse effect on transplanting; this might unfairly result in transplanting being recommended against.

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Institutional Review Board Statement: The Ethical Committee of the Midlands State University, Zimbabwe has granted approval for this study on 1 December 2020 (Ref. No. 0093).
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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