African Crop Science Journal, Vol. 31, No. 2, pp. 191 - 199
ISSN 1021-9730/2023 $4.00

DOI: https://dx.doi.org/10.4314/acsj.v31i2.5

OPTIMUM COMBINATION OF PLANT SPACING AND MULCHING ON PRODUCTIVITY OF RED-LEAF LETTUCE

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(*Received 10 September 2022; accepted 2 January 2023*)

ABSTRACT

Lettuce (*Lactuca sativa* L.) is increasingly a popular vegetable salad, especially in the tropics where it is reputed for providing health benefits such as lowering cholesterol levels, fighting insomnia, preventing growth of cancerous cells and providing antioxidants. In Uganda, its yields are suboptimal, reportedly due to poor agronomic practices. The objective of this study was to determine the optimum combination of planting density and mulching of red-leaf lettuce under Uganda field conditions. A field experiment was conducted at the Agromax Uganda Limited farm in Kampala in 2018. The study involved two treatments, namely mulching using black polythene and varying intra-row spacing (15, 25 and 35 cm), all against inter-row spacing of 40 cm. The treatments were laid out in a split plot arrangement, in a randomised complete block design, with three replications. The main plot factor was mulching; while the subplot treatment was plant spacing. The interaction effect of plant spacing and mulching with polythene was significant ($P<0.05$) on plant heights, number of leaves per plant, leaf length and breadth, and fresh weight. Mulching at the widest intra-row spacing (35 cm) resulted in shorter plants (22.9 cm) with the highest leaf numbers per plant (23.6), longest and widest leaves (21.8 and 19.5 cm, respectively); and consequently the highest fresh yield (381.3 g m^{-2}). It is, therefore, prudent that this plant spacing and plastic mulching be on a wider scale to validate the results across the country.

Key Words: *Lactuca sativa*, leaf length, plant height, planting density

RÉSUMÉ

La laitue (*Lactuca sativa* L.) est une légume qui est plus utilisé pour le salade, elle est particuriellement populaire sous les tropiques où elle est réputée pour ses bienfaits pour la santé tels que la réduction du taux de cholestérol, la lutte contre l'insomnie, la prévention de la croissance des cellules cancéreuses et la fourniture d'antioxydants. En Ouganda, ses rendements sont sous-optimaux, apparemment en raison de mauvaises pratiques agronomiques. L'objectif de cette étude était de déterminer la combinaison optimale de la densité de plantation et du paillage de la laitue à feuilles rouges dans les conditions de terrain de l'Ouganda. Une expérience sur le terrain a été menée à la ferme Agromax

Uganda Limited à Kampala en 2018. L'étude impliquait deux traitements, à savoir le paillage à l'aide de polyéthylène noir et un espacement variable entre les rangs (15, 25 et 35 cm), le tout contre un espacement entre les rangs de 40 cm. Les traitements ont été disposés dans un arrangement de parcelles divisées, dans une conception en blocs complets randomisés, avec trois répétitions. Le principal facteur de la parcelle était le paillage; tandis que le traitement des sous-parcelles était l'espacement des plantes. L'effet d'interaction de l'espacement des plantes et du paillage avec le polyéthylène était significatif (P<0,05) sur la hauteur des plantes, le nombre de feuilles par plante, la longueur et la largeur des feuilles et le poids frais. Le paillage à l'espacement intra-rang le plus large (35 cm) a donné des plantes plus courtes (22,9 cm) avec le plus grand nombre de feuilles par plante (23,6), les feuilles les plus longues et les plus larges (21,8 et 19,5 cm, respectivement); et par conséquent le rendement frais le plus élevé (381,3 g m^{-2}). Il est donc prudent que cet espacement des plantes et ce paillage plastique soient à plus grande échelle pour valider les résultats à travers le pays.

Mots Clés: *Lactuca sativa*, longueur des feuilles, hauteur de la plante, densité de plantation

INTRODUCTION

Lettuce (*Lactuca sativa* L.) is increasingly a popular vegetable salad, especially in the tropics where it is reputed for providing health benefits such as lowering cholesterol levels, fighting insomnia, preventing growth of cancerous cells and providing antioxidants (Mampholo *et al*., 2016; Hasan *et al*., 2017; Yang *et al*., 2021). It belongs to the *Asteraceae* family, and produces crispy leaves, rich in fatty acids (linolenic and linoleic acids), vitamins A, B9, C, E and K and minerals like calcium, potassium, magnesium, iron, zinc and copper, as well dietary fibre (Mulabagal *et al*., 2010; Sularz *et al*., 2020).

Lettuce is a cool-season vegetable crop that prefers optimal atmospheric temperature of 23 ^{o}C and root temperature of 19 ^{o}C (Fazil Elahi *et al*., 2017). Ferreira *et al*. (2014) reported that high temperatures reduce the photosystem efficiency of the crop, leading to photo-inhibition and consequently low yields. However, through breeding, varieties that are adapted to tropical weather conditions have been developed, and the most common examples currently grown in Uganda include butter-head, crisp-head, romaine and loose-leaf (Asiimwe, 2015).

In Uganda, the productivity of this crop is still low mainly due to poor agronomic practices and lack of sufficient knowledge and skills needed to successfully grow it. Farmers use plant spacing ranging from 20 to 50 cm for inter-row; and 20 to 45 cm for intra-row spacing, irrespective of differences in varieties, soil type and various agronomic conditions. Absence of standard plant spacing for lettuce under specific conditions has rendered farmers to plant the crop haphazardly and ineptly, thus leading to poor yields. Optimum plant spacing ensures efficient use of growth resources, namely soil nutrients, moisture, light and space, which ultimately benefit yields (Khazaei *et al*., 2013). Plant densities greater than the optimum result in a drop in yields due to competition for growth resources; while low plant densities below the optimum also lead to reduced yields due to under-utilisation of growth resources by the sparsely spaced plants (Aminifard *et al*., 2010).

A more recent factor that has drastically affected widespread production of lettuce in the tropics is the rampant vagary in rainfall, largely due to climate change. Being a succulent vegetable, lettuce requires plenty of water for normal growth and development (Gallardo *et al*., 1996). Thus, its production could be improved by better soil moisture management practices, such as use of effective mulching. There are many types of materials, both organic and inorganic, that can be used as mulch in horticulture. Plastic materials are commonly used, especially in vegetable and fruit growing, owing to the growing scarcity of vegetative biomass. The objective of this study was to determine the optimum combination of plant spacing and mulching of red-leaf lettuce for targeted yield under Uganda rain-fed conditions.

MATERIALS AND METHODS

Study site. A field experiment was conducted for two seasons in 2018, at the farm of Agromax Uganda Limited, Kampala in Uganda. The farm is located at 0° 14'32' N and 32° 37'29' E and at an altitude of 1160 metres above sea level. The area experiences average annual temperature of 24 °C and receives up to 1150 mm of rainfall annually. The soils are classified as sandy-clay loam with pH 6.6 (Fungo *et al.,* 2011).

Treatments and experimental design. Treatments comprised of mulching at two levels, using black polythene sheets and no-mulching as the control; and plant spacing at three levels, namely 40 cm x 15 cm, 40 cm x 25 cm and 40 cm x 35 cm. The experiment was laid in a randomised complete block design with three replications, in a split plot arrangement. Mulching formed the main plot; while plant spacing formed the subplot treatment.

A unit plot size was 1.6 m x 7.2 m and the strips between blocks and plots were 0.7 and 0.5 m, respectively. Red-leaf lettuce seedlings were planted in the plots at the inter-row spacing of 40 cm; while the intra-row spacing between plants within the rows were 15, 25 and 35 cm.

Nursery bed stage. Seeds of red-leaf lettuce were obtained from the East African Seeds Company Limited and raised into seedlings at Agromax in the nursery bed. The nursery bed was first ploughed to remove weeds and stubbles. A nursery bed of 3 m x 1 m was demarcated and 5 kg of composted animal manure incorporated into the bed prior to sowing the seeds. Then a fungicide (Indofil M-45) was applied to control damping off disease.

The red-leaf lettuce seeds were sown in shallow furrows and covered lightly with soil. The beds were then mulched with sun dried grass and watered regularly. The mulch was removed after seedling emergency, to expose them to sunlight. After five weeks in the nursery, the seedlings were hardened for one week before being transplanted to the field.

Main field activities. The experimental site was ploughed thoroughly and partitioned into unit plots, each of 1.6 m x 7.2 m. The topsoil (20 cm depth) in the plots was treated with the fungicide Indofil M-45 to prevent fungal attack on the seedlings after transplanting. Then, a black polythene sheet of 0.2 mm thickness was laid on top of the soil surface in the plots designated for the mulching treatments. Healthy and uniformly sized seedlings of approximately 5.0 cm height, were carefully transplanted from the nursery into the plots, in the afternoon to guard against transplanting shock. To minimise damage to the roots, the seedlings were first watered while still in the nursery bed, one hour before uprooting them. The seedlings were further watered every evening for two weeks after transplanting, to ensure sufficient moisture availability for normal growth.

Data collection and analysis. Data were recorded for plant height, leaves per plant, leaf length and breadth; and fresh leaf weight per plant. All these measurements were taken at 30, 45 and 60 days after transplanting (DAT). At every round of data collection, five plants were selected randomly from the inner rows in each plot for data collection. Outer rows and plants at the extreme ends of the middle rows were excluded from data collection to avoid border effects.

Plant height was measured from ground level up to the tips of growing points of the selected plants, using a measuring tape. The lengths and breadths of leaves of selected plants were also measured using a ruler. During the first round of data collection, at 30 DAP, three fully developed leaves below the shoot tip of every plant were measured, while during the second and third rounds of data collection, the lengths and widths of only newly formed leaves were measured. The yield of red-leaf lettuce per plot was assessed from the weights of five plants harvested from the plot.

All the data collected were keyed in Microsoft Excel sheet and subjected to analysis of variance using GenStat software, 12th Edition. Significant treatment means were separated using Fisher's Least Significance Difference (LSD) at 5% level of significance.

RESULTS

Plant height. The combined effect of spacing and plastic mulching was significant (P<0.05) on plant height (Table 1). In both mulched and un-mulched treatments, plant height significantly (P<0.05) decreased as the intra-row spacing increased from 15 to 35 cm. Generally, the mulched plants were taller and healthier-looking than un-mulched counterparts. Significantly shorter plants were obtained at the widest intra-row spacing (35 cm) when compared with other treatments at each level of mulching, while the closest intra-row spacing (15 cm) gave the tallest plants.

Number of leaves per plant. In both the mulched and un-mulched treatments, the number of leaves per plant significantly (P<0.05) increased as the intra-row spacing increased from 15 to 35 cm (Table 1). The numbers of leaves per plant produced at the intra-row spacing of 25 and 35 cm in both the mulched and un-mulched treatments were similar, but higher (P<0.05) than those produced by plants spaced at the closest spacing (15 cm). With the exception of plants that were spaced at 40 cm x 15 cm, the number of leaves per plant in the mulched treatments was greater (P<0.05) than that of un-mulched treatments.

Leaf length and breadth. At each level of mulching, the leaf lengths and breadths significantly (P<0.05) increased as the intra-

TABLE 1. Combined effect of mulching with black polythene and plant spacing on the growth traits of red-leaf lettuce

Treatment combination		Growth traits			
Mulching	Spacing (cm)	Plant height (cm)	Number of leaves	Leaf length (cm)	Leaf breadth (cm)
Un-mulched	40 x 15	23.7^{c}	19.6^{c}	15.8^{f}	13.9^{e}
	40 x 25	21.6^{e}	22.3^{b}	17.8^{e}	17.0^{d}
	40 x 35	18.9^{f}	22.4^{b}	19.1^{d}	17.8^{c}
Mulched	40 x 15	26.5^{a}	22.5^{b}	20.1^{c}	17.7^{c}
	40 x 25	24.8^{b}	23.3^{a}	20.5^{b}	18.9^{b}
	40 x 35	22.9^{d}	23.6^{a}	21.8^{a}	19.5^{a}
Mean		23.1	22.3	19.2	17.5
P-value		<0.001	<0.001	<0.001	<0.001
$LSD_{(0.05)}$		0.3	0.3	0.3	0.4

^{abc}Means within the same column having different superscripts are significantly (P<0.05) different; LSD = Least Significant Difference row spacing increased from 15 to 35 cm (Table 1). However, the leaf lengths of mulched plants were greater than those of un-mulched plants. Mulched plants at the widest intra-row spacing (35 cm) produced the longest leaves (21.8 cm) compared to the rest of the plants, both in the mulched and un-mulched treatments; while those that were planted at the closest intra-row spacing (15 cm) and un-mulched produced the shortest leaves (15.8 cm).

The greatest leaf breadth (19.5 cm) was recorded in mulched plants that were widely spaced (40 cm x 35 cm), and this was followed by mulched plants that were spaced at 40 cm x 25 cm, with a breadth of 18.9 cm. Un-mulched plants that were widely spaced (40 cm x 35 cm) generally had shorter leaf breadths than the mulched plant counterparts.

Fresh leaf yield. At each level of mulching and at each growth stage (30, 45 and 60 DAT), fresh leaf weights of plants significantly ($P<0.05$) increased with the increase in intra-row plant spacing (Table 2). With the exception of mulched plants that were closely spaced (40 cm x 15 cm), the fresh leaf weights of mulched plants that were planted at the intra-row spacing of either 25 or 35 cm were greater ($P<0.05$) than those of plants from the un-mulched treatments across all the stages of growth, as well as the overall means (Table 2). Mulched plants that were planted at the widest spacing (40 x 35 cm) produced the highest mean yield (381.3 g m^{-2}) compared to all the other mulched and un-mulched plants; while the closest spacing of 40 cm x 15 cm in both the mulched and un-mulched treatments gave the lowest mean yields (228.9 and 255.8 g m^{-2}, respectively).

DISCUSSION

Plant height. The decrease in plant heights as the intra-row spacing increased, irrespective of mulching status (Table 1), could be attributed to reduced competition for growth resources by the plants, especially sunlight. At the closest intra-row spacing (15 cm), plants grew taller perhaps to access sunlight (etiolation), but as the intra-row spacing

TABLE 2. Combined effect of mulching and plant spacing on fresh yield (g m^{-2}) of red-leaf lettuce at different growth stages

Treatment combination		Days after transplanting (DAT)			Mean
Mulching	Spacing (cm)	30	45	60	
Un-mulched	40 x 15	180.0^{f}	237.5^{e}	269.1^{f}	228.9^{f}
	40 x 25	252.9^{d}	309.8^{c}	339.8^{d}	300.8^{d}
	40 x 35	301.2^{c}	360.0^{b}	388.3^{c}	349.8^{c}
Mulched	40 x 15	215.2^{e}	262.3^{d}	289.8^{e}	255.8^{e}
	40 x 25	311.5^{b}	360.6^{b}	389.3^{b}	353.8^{b}
	40 x 35	340.2^{a}	387.1^{a}	416.7^{a}	381.3^{a}
Mean		266.8	319.5	348.9	311.7
P-value		<0.001	<0.001	<0.001	<0.001
$LSD_{(0.05)}$		0.6	0.7	0.7	0.3

^{abc}Means within the same column having different superscripts are significantly ($P<0.05$) different; DAT = Days after transplanting; LSD = Least Significant Difference increased, the competition for light reduced, hence leading to healthier growth (Khazaei *et al*., 2013; Alahi *et al*., 2014).

The results also revealed that mulched plants were taller and healthier-looking than their un-mulched counterparts. This could have been due to additional soil moisture conserved by the mulch and later utilised by lettuce plants. Although not monitored in the present study, mulching is known to conserve moisture in the root zone, which is subsequently used by the crop to offset vagaries in soil moisture supply due to unreliable rainfall (Asaduzzaman *et al*., 2010). Mulching also suppresses weeds that would compete with crops for nutrients and moisture, and modifies soil temperature making the rhizosphere microclimate more suitable for crop growth (Siwek *et al*., 2007; Yordanova and Gerasimova, 2015; Ahmad *et al*., 2015).

Plastic mulches have been reported to provide multiple benefits, including serving as a physical barrier against soil erosion, reducing water evaporation from soil, buffering against temperature fluctuations, suppressing weeds, and improving foliage quality (Davari, 2016; Gheshm and Brown, 2020). Mulch films modify soil temperature by altering the flow of thermal energy between the air and the top soil layer (Tarara, 2000; Lamont, 2005). Pramanik *et al*. (2015) observed that soil temperature under plastic mulch depends on the optical properties of the mulch material, and each material has a different reflectivity and absorptivity. They concluded that dark and black coloured plastic mulches absorb more solar radiation, hence making the soil temperature higher than in soils under white coloured plastic mulches.

Number of leaves per plant. The increase in number of leaves per plant, in both the mulched and un-mulched plants (Table 1), could have resulted from improved soil microclimatic conditions, particularly soil water and temperature, that are needed for leaf development in plants (Tosic *et al*. (2014; Tesfa *et al.,* 2018). Similarly, higher leaf numbers per plant in mulched plants spaced at the medium and widest spacing, could be due to greater conservation of moisture by the poly mulch, which subsequently enhanced the availability and utilisation of nutrients by the plants (Tesfa *et al.,* 2018; Gheshm and Brown, 2020). Extended soil moisture conservation, amidst raised soil temperatures usually accelerates the rate of inherent organic matter breakdown by soil organisms, hence releasing more nutrients that become available to plants for uptake (Gougoulias *et al*., 2014; Fazil Elahi *et al*., 2017). Fazil Elahi *et al*. (2017) observed that optimal ambient root zone temperature has an effect on the assimilation partitioning, as well as water and nutrient uptake by lettuce. These effects may ultimately result in greater numbers of leaves produced per plant. Allison *et al*. (2010) also reported a positive effect of poly mulch on soil temperature which may have enhanced the rate of organic matter decomposition and mineralisation, as well as affecting soil water content, its conductivity and availability to plants.

Leaf lengths and breadths (leaf size). Like in the case of other growth parameters discussed above, the lengths and breadths of lettuce foliage were positively promoted by mulching when accompanied by wider intra-row distances (Table 1). Again, this could be attributed to greater improvement of black poly mulch on soil microenvironment widely associated with superior morphological development in lettuce and other vegetable crops (Davari, 2016; Tesfa *et al.,* 2018; Gheshm and Brown, 2020). Additionally, the wider intra-row spacing could have enabled the lettuce plants to access more sunlight that enhanced the photosynthetic process, leading to the production of more photosynthates for growth and development (Khazaei *et al*., 2013). These findings are also in conformity with those of Mutetwa and Mtaita (2014) on cucumber and Kwambe *et al.* (2015) on lettuce. Kwambe *et al.* (2015) attributed the increase in leaf length to soil moisture conservation by the black polythene that eventually promoted nutrient uptake by the plants. Mulching lettuce plants using black polythene thus bears potential for increased foliar leaf production, although the economic benefits accruing from the associated investment still require appropriate investigation.

Fresh leaf mass. The increase in fresh leaf yields in response to combined effect of mulching and increasing intra-row spacing (Table 2), could have resulted from enhanced utilisation of resources, particularly soil nutrients, sunlight and moisture, which was also facilitated by other factors like favourable temperature and hastened microbial activity (Tesfa *et al.*, 2018; Gheshm and Brown, 2020). In the mulched treatments, the black polythene created appropriate conditions (soil temperature and moisture, and suppressed weed growth) for optimal growth of lettuce, which were further supported by reduced competition as spacing increased (Davari, 2016; Hasan *et al.*, 2017; Mengistu *et al.*, 2021). Hasan *et al.* (2017) reported greater total yields per hectare at optimum spacing (low plant population), which they attributed to higher individual plant weight, as optimum spacing promoted maximum vegetative growth. Sharma *et al.* (2001) recorded a gradual increase in the yield per plant, being minimum at the closest spacing of 30 cm x 30 cm, and optimal when the spacing was increased to 45 cm x 30 cm. A further increase in spacing to 60 cm x 45 cm gave the highest fresh yield per plant due to reduced competition, but the yield per hectare declined. Thus, as the spacing increases, the weights of individual plants increase due to accelerated vegetative growth, which in turn leads to higher yields per hectare.

CONCLUSION

It is clear from this study that the performance of red-leaf lettuce can be improved greatly through management of plant spacing along with mulching using black polythene mulch. The best treatment combination is when mulching is done at the pacing of 40 cm x 35 cm. However, prior to scaling out this recommendation to farmers, there is need for assessment of the cost/benefit analysis to determine the economic viability associated with the additional investment.

ACKNOWLEDGEMENT

The authors wish to acknowledge Agromax Uganda Limited for providing the facilities that enabled execution of this study.

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