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Department of Plant and Horticultural Sciences

Nitrogen rate, Plant Density and Weeding effect on Weed Dynamics and Yield of Onion (*Allium cepa* L) under Irrigated Condition in Enderta District, Tigray, Northern Ethiopia

A Thesis By:

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Declaration

This is to certify that this thesis entitled "Nitrogen rate, Planting Density and Weeding effect on Weed Dynamics and Yield of Onion (*Allium cepa L*) under Irrigated Condition in Enderta District, Tigray, Northern Ethiopia" submitted in partial fulfillment of the requirements for the award of the Degree of M.Sc. in Horticulture Sciences to the School of Graduate Studies, Mekelle University, through the Department of Dryland Crop and Horticultural Sciences, done by Mrs. Birtukan Gebrekiros is an authentic work carried out by her under our guidance. The matter embodied in this thesis work has not been submitted earlier for award of any degree or diploma to the best of my knowledge and belief.

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Dedication

I dedicate this thesis manuscript to my Grand Mother Bezu Enune who brought me success in my life and to my children Birkti Haftamu and Fikrte Haftamu.

Biographical Sketch

Birtukan Gebrekiros was born in July 23, 1994 in Mekelle capital city of Tigray Regional State, Ethiopia. From her father Ato Gebrekiros Gebreezabher and her mother W/ro Mebrat Gidey. She attended her elementary education at Aynalem Elementary School and secondary school at Adi- Haki compressive secondary school, Mekelle. In 2012, she completed her high school education and then joined Mekelle University, graduated in June 2015 with B.Sc. Degree in College of Dryland Agriculture and Natural Resources Department of Dryland Crop and Horticultural Sciences. Soon after graduation, she joined Tigray Agricultural Research Institute (TARI) in March, 2016. in her stay at TARI, she worked as Junior Researcher at Alamata Agricultural Research Center until she joined Mekelle University. She joined the school of graduate studies of Mekelle University in October 2020 to pursue her MSc Study in the field of Horticulture.

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List of Abbreviation

ANOVA	Analysis of Variance
AVADC	Asia Vegetable Research and Development Centre
BD	Bulk Density
CEC	Cation Exchange Capacity
cm	Centi meter
CSA	Central Statistics Authority
EARO	Ethiopian Agriculture Research Organization
FAO	Food and Agriculture Organization
FC	Field capacity
g	Gram
ha	Hectare
Kg	Kilogram
m.a.s.l	Meter Above Sea Level
mm	Millimeter
MoARD	Ministry of Agriculture and Rural Development
N	Nitrogen
OC	Organic Carbon
Om	Organic Matter
P	Phosphorus
ppm	Parts per million
PWP	Permeant wilting point
TN	Total Nitrogen
TSP	Triple Super Phosphate
TSS	Total Soluble Solid
Tukey HSD	Honestly Significant Difference

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ABSTRACT

In Ethiopia, onion is grown mainly for its bulbs which is commonly used for daily diet and is consumed in every home in different ways. It is used as a seasoning or a vegetable in various dishes. For small-scale farming community, it serves as source of income. Weeds coupled with inappropriate application of N and non-optimal planting density are among the factors constraining onion production. A field experiment was conducted at Mekelle university research site, to evaluate the effect of N rates, planting density and hand weeding on weed dynamics and yield of irrigated onion. The experimental design was a split- plot with three blocks where main plots were hand weeding (with and without) and the sub plots were the combination of N fertilizer rates (0kg N/ha, 23Kg N/ha, 46Kg N/ha and 69Kg N/ha) and Planting density (222,222, 333,333 and 666,666 plants/ha). Results revealed 24 major weed species in the fields of onion. These identified weed species fell into 14 different families,among the 24 species the most dominant weed species affecting onion growth, development and productivity are Lanuaea capitata (spreng)Dandy, Anagallis arvensis L, Argemone Mexicana, Galinsogo parviflora Cav, Setaria pumila (poir.) Roem. & schuh, and Colchicum alpinum DC. Hand weeding had significant effect on all weed parameters. Maximum weed density (211no/m^2), weed dry weight (298g/m^2) and weed cover (61%), was recorded from weedy plots. Hand weeding had significant effect on most of the growth parameters, except on root length. Higher leaf number (9 cm), leaf length (40 cm) leaf diameter (0.95 cm), plant height (40 cm) and prolonged days to maturity was found from hand weeded plots. Hand weeding also significantly affected almost all yield, yield components and quality except on unmarketable yield and total soluble solid (TSS). The highest bulb weight (59g), bulb length (5cm), bulb diameter (4.6 cm), neck diameter (0.50 cm), and bulb dry matter (37.4 g) were found from hand weeded plots. In addition, maximum marketable yield (9965 kg/ha), total bulb yield (9992 kg/ha) were recorded from weeded plots. Higher bulb shape index (1.3) which is considered as non-desirable was found on weedy plots. Plant density had significant effect on leaf length, bulb weight, bulb diameter as well as bulb shape index. The highest leaf length (33.7cm), bulb weight (53.6g), and bulb diameter(4.4cm) was obtained at high plant density from hand weeded plots. Onion bulbs had highest shape index (1.2) at plant density of 333,333 plants/ha on hand weeded plots. Likewise, N rate had significant effect on days to 90% maturity and bulb length. The highest bulb length (5cm) was recorded from hand weeded plots received 46kg N ha-^{1}. Onion maturity was delayed when N was applied at a rate of 69 kg N ha-^{1} on hand weeded plots. Except hand weeding, all other factors did not have significant effect on onion marketable yield, unmarketable yield and total bulb yield. Maximum marketable yield (9,965 kg/ha) was obtained from hand weeded plots and the lowest marketable yield (4758) was recorded from un weeded plots. Generally, weeds cause a yield loss of (52.2) %. In conclusion, weed species found in onion field were comprised of a wide range of annual species in life cycle and broad leaf in nature of growth habit. Hand weeding resulted in weed dynamics and shifted weed-crop competition advantage in favor of the crop. It influenced the crop throughout its growth and development. Variation in amount of N rate fertilizer resulted in weed dynamic and influenced only bulb length. However, plant density did not have visible effect on weed and the crop's growth, development and productivity. In recommendation. The experiment has to be repeated in more location and season to make a conclusive recommendation.

Key words: *Onion, Hand weeding, Planting density, N rate, Marketable yield,*

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Onion (*Allium cepa* L.) belongs to the genus Allium of the family Alliaceae (Hanelt, 1990; Griffiths et al., 2002). It is considerably important in the daily Ethiopian diet, mostly used as seasonings or as vegetables in stews (MoARD, 2009). It is one of the richest sources of flavonoids in the human diet which has been associated with a reduced risk of cancer, heart disease and diabetes. In addition, it is known for anti-bacterial, anti-viral, anti-allergenic and anti-inflammatory potential (Lemma and Herath, 1992).

Onions are spread throughout Ethiopia being cultivated under both irrigated as well as rain fed conditions in different agro climatic regions. The crop is suited in low to mid-altitude regions, thriving at elevations up to 2000 meters above sea level (m.a.s.l). However, the optimal growing altitude ranges between 700 and 1800 m.a.s.l (Aklilu,1997 and Lemma et al, 1994). Alliums are typically plants thrive in open, sunny dry sites within fairly arid climates, however many species can also be found in the steppes, dry mountain slopes, rocky or stony open sites, and summer dry, open, scrubby vegetation (Hanelt, 1990). The species shows a great diversity in form, color, shape, dry matter content and pungency, reflects the success of the species in adapting to a wide range of environments (Griffiths et al.,2002).

Onion is by far the most important of the bulb crops cultivated commercially in nearly most parts of Ethiopia and ranks third after red pepper and kale in terms of area coverage (CSA, 2018). It is estimated that globally, over 3,642,000 ha of onions are grown annually producing approximately 80 million metric tons of onions. China is by far the top onion producing country in the world, accounting approximately 28% of the world’s onion production, followed by India, USA, Iran, Egypt, Turkey, Russia, Pakistan, Netherlands and Brazil. Worldwide onion exports are estimated around 7 million Metric tons. The Netherlands is the world’s largest onion exporter with a total of around 220,000 Metric tons followed by India (FAO, 2013).

Onion is one of the most popular and most cultivated vegetables in Ethiopia in general and in Tigray region in particular (Hailu et al., 2015). It is widely produced by small scale farmers and commercial growers throughout the year for local use and export market.

Onion plays a significant economic role in Ethiopia. The crop contributes to the national economy of Ethiopia through its high value cut flowers, premium priced seeds and edible bulbs. Furthermore, onion production creates huge employment opportunities as it needs intensive management and skilled labor. Onion production in the country is increasing from time to time due an increase of small-scale irrigation, its high profitability per unit area and ease of production, (Nikus and Fikre ,2010). Ethiopia, the third largest producer of onion in the African continent next to Egypt and South Africa, During the 2021/2022 cropping season, around 36.4 million hectares of land were allocated to onion cultivation, resulting in a harvest of approximately 346,048.1 tons, with a productivity rate of 8.9 t/ha-^{1}. The average production onion in Ethiopia is 8.9 t/ha-^{1}, lower than global averages of 19.1t/ha-^{1} and 35.5 t/ha-^{1} in Egypt, and 18 t/ha-^{1} in Sudan (CSA,2021 and FAOSTAT,2021). Within Ethiopia, the highest production of onion is recorded from Oromia Region 19.2 t/ha-^{1} followed by the Amhara Region 12.3t/ha-^{1}.

According to (CSA, 2019), at proximately 28,682 smallholder farm households in Tigray were engaged in the production of onion. These households produced 8,223 tons of onion on 1,299.06 hectares with average productivity of 6.33 tons/ha which is less than the national average yield of 9.32 tons/ha in the same season. There are various production constraints that decrease the seed and bulb yield onion in the country in general and in Tigray region in particular. These constraints include weeds**,** insect pests and diseases, lack of improved agronomic practices (in relation to optimization of input and plant population), limited availability of improved high yielding and adaptable varieties, seed availability, poor post-harvest handling and insufficient extension services (Lemma and Shimeles, 2003).

Optimum plant spacing and nitrogen recommendations have been formulated for onion particularly in the Rift Valley region of Ethiopia, which is double row spacing of 10 cm between plants and 20 cm between rows and application of 46 kg N ha^{-1} and 92 kg P2O5 ha^{-1} (Lemma and Shimeles, 2003) and (Nikus and Fikre, 2010). However, these recommendations cannot be directly adopted to any soil conditions, which is different from those in the Rift Valley region. Generally, as most agronomic recommendations are site specific, it is very challenging to provide recommendations that are applicable across different agro-ecological zones. In particular, the impact of N-fertilizer, plant population and weeding on weed dynamics and onion yield is not/less covered and investigated.

Weed causes a serious effect on the size of onion yields and it is identified as a major bottle neck in vegetable crop production next to diseases and insect pests (Lemma and Shimeles, 2003; Haile et al., 2016). Weed compete with onion for light, nutrient, water, space and also act as host plant of several harmful insects and pathogens and considerably reduce the yield, quality and value of the crop through increased production and harvesting costs (Uygur et al., 2010). The current research was therefore, initiated to determine the optimum level of N and population density for onion, and to study the effect of weed dynamics in the crop.

1.2. Statement of problem

Urban agriculture in Mekelle, the capital city of Tigray, and its surrounding areas is expanding, marked by intensive and extensive onion production. These areas are significantly contributing to the onion supply in the local vegetable markets. Nevertheless, the major bottlenecks of onion production in the area include unoptimized N fertilization and planting density as well as pests. Among the pests, weeds affect yield and quality of onion as they compete with crops for resources like light, water, nutrients, and space during production. Weeds are also host plants for several harmful insects and pathogens (Ghoshel, 2004, Qasem, 2006, Smith et al., 2008). Furthermore, as in many crops, weeds cause yield reduction in onions owing to slow emergence, low initial growth rate, long vegetative period, and low competitive ability of the crop (Boyham et al., 2016). In general, weeds reduced onion yield 68 up to 73% of the total production in Ethiopia (Etageneghu and Ahemed, 1985; Lemma and Shimeles, 2003; Grief, 2015). However, the effect of weeds on onion production and productivity is not considered and studied very well in the study area.

As a heavy feeder, onion require optimum amount of nitrogen which is determined based on its impact on the final bulb yield, without considering its effect on weed incidence and severity. One of the objectives of this research was therefore to investigate this effect.

Onions competes not only with weeds but also with neighboring onion plants growing in close proximity. This is caused due to unoptimized plant population in specific area, where this study is aimed to deal with. This study was initiated to determine the combined effect of the various levels of N-fertilizer and plant density (spacing) on both weed dynamics and yield of onion.

1.3. Objective

1.3.1. General objective

- ❖ Determine the optimum amount of N-fertilizer rate and plant density for low weed competition and high onion productivity under irrigated water.

1.3.2. Specific objectives

- ❖ Elucidate the effect of variability of N-fertilizer rate on weed dynamics and onion productivity.
- ❖ Determine optimum plant density of onion, which can result in low weed competition and high onion productivity.
- ❖ Examine the combined effect of the different amount of N-fertilizer rate and plant density on weed dynamics and onion productivity.

1.4. Hypotheses of the Experiment

H1:

- ➢ Hand weeding and variation in N- level and planting density affect weed dynamics and onion productivity.

1.5. Significance of the study

- This study will provide information on the N rate, plant density and weed effect on onion weed dynamic and yield. The output from this study will benefit also serve as a source of information that could be of significant for farmers, researchers, policy makers and planners at regional and national.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Description of onion crop

Onion is among the most widely adapted vegetable crops. It can be grown in a wide range of climatic environments, but it thrives best at mild climate without excessive rainfall or extremes of heat and cold (Lemma,2004 and Lemma et al.,2006). Onion is a cool season crop that has some frost tolerance but is best adapted to a temperature range between 13 and 24^0c. (Demis,2021).

Onions are sensitive to photoperiod and are grouped into short-days and long-days depending on the day length requirements. The bulbs that acquire day length of 11.5 hours are categorized into short-day group and those take 14 hours or more for bulb formation fell into long-day group. Onion also requires varying day length and temperature for the purpose they produced. A relatively high temperature and long photoperiod are required for bulb formation, and for seed production, temperature is of immense importance than day length. Onion bulbs have specific temperature requirement for seed and bulb production (Baloch, 1994).

Onion is a highly cross-pollinated crop due to protandry in nature, the flowers cannot fertilize themselves since pollens are shed by anthers even before the stigma becomes receptive (Desh,2018; Delaplane and Mayer, 2000). However, some variations exist among cultivars, the number of flower stalks produced by single onion ranged from 3- 12 and it produces about 250 to 1000 flowers per umbel under mid altitude area (Desalegn and Aklilu,2003).

2.2. Importance, production requirement and status of onion in Ethiopia

Importance

The production of vegetables is becoming important with the expanding irrigated agriculture and with the growing awareness on the importance of the sector as source of income, improved food security, sources of raw materials for industries, employment opportunity because it demands large labor force. However, the success of production depends on the adoption of improved technologies such as cultivars that have acceptable standard and high value in the local use and export markets (Lemma et al., 2006). Onion is a high-value bulb crop among the vegetables that has produced by smallholder farmers and commercial growers on large scale for both local and export markets in Ethiopia (Shimeles,1994). It also occupies an economically important place among vegetables in the country.

Onion is important in the daily Ethiopian diet and all the plant parts are edible, although the bulbs are widely used as a seasoning or a vegetable in various dishes. Onion is valued for its distinct pungency and form essential ingredients for flavoring varieties of dishes, sauces, soup, sandwiches, snacks as onion rings etc. It is popular over the local shallot because of its high yield potential per unit area, availability of desirable cultivars for various uses and ease of propagation by seed (Lemma, 2004).

Production requirement

Onions can be grown on a wide range of soils, varying in texture from coarse-grained sands to clays. Lighter soils are easy to manage. Soils should be 45-60 cm deep and well drained. Soils with high water holding capacity are better able to provide moisture to the shallow rooting system but must also drain well to be suitable. Growth is retarded when available soil moisture is low, but onions are also sensitive to a high-water table or water logging. Uniform moisture availability about 400-800mm per crop is conducive to large bulb size and high yields. Favorable soil pH is about 6.5–8.0 in mineral soils (Rubatzky and Yamaguchi,1997; Savva and Frenken,2002).

Production

Ethiopia has a great potential to produce onion throughout the year both for local consumption and for export. It grows best at an altitude of between 700-2200 meters above sea level. Onion is a rapidly becoming popular among producers and consumers. Its popularity among producers is because of the advantage of high yield potential, availability of desirable cultivars for various uses, ease of propagation by seed, high domestic (bulb and seed) and markets in fresh and processed forms (Lemma and Shimeles, 2003). The area under onion is increasing from time to time mainly due to its high profitability per unit area and ease of production, and the increases in small scale irrigation (Nikus and Fikre,2010). Ethiopia is the largest onion producer in Sub-Saharan Africa, with vast potential for onion production. Around 36.4 million hectares of land are allocated to onion cultivation, resulting in a harvest of approximately 346,048.1 tons of bulbs, with a productivity rate of 8.9 tons per hectare. Most of the onion production (73%) is consumed by farm households, while 26% is sold in the market and 1% is used for seed purposes (CSA,2021).

The average onion production intensity in Ethiopia is 8.9 tons per hectare, lower than global averages of 19.1 tons per hectare; and 35.5 tons per hectare in Egypt, and 18 tons per hectare in Sudan (CSA,2021 and FAOSTAT,2021). Within Ethiopia, the Oromia Region leads in onion production with a rate of 19.32 tons per hectare, followed by the Amhara Region. The Amhara Region contributes around 50% of the national onion production, with a productivity rate of 12.3 tons per hectare. onion was grown by 28,682 smallholder farm households in Tigray. These households produced 8,223 tons of onion on 1,299.06 hectares with average productivity of 6.33 tons/ha which is less than the national average yield of 9.32 tons/ha in the same season (CSA, 2019).

2.3. Role of nitrogen in onion crop

Nitrogen is most imperative element for proper growth, development, biochemical and physiological functions of plant. Nitrogen is an integral component of many essential plant compounds. This nitrogen is needed to form chlorophyll, proteins and it is a major part of all amino acids and many other molecules essential for plant growth and other critical nitrogenous plant components such as the nucleic acids and chlorophyll (Brady and Weil ,2002).

Plants utilize nitrogen in the form of nitrate ($N0_3^-$) or ammonium ($NH4^+$). It is one of the most complexes in behavior, occurring in soil, air and water in organic and inorganic forms. Due to this reason, it poses the most difficult problem in making fertilizer recommendations (Archer, 1993).

N is highly soluble in water and hence susceptible to leaching, potentially contributing to environmental contamination. Also, N can be lost via denitrification, especially from water logged soils (Oweis *et al*., 1998). Nitrogen in the plant controls the utilization of phosphorus and potassium and excess could delay maturity by causing too much vegetative growth (Guatfson,2010). Nitrogen is also essential for carbohydrate use within plants (Nasreen et al, 2007). A good supply of nitrogen stimulates root growth and development as well as the uptake of other nutrients (Brady and Weil ,2002).

2.4. Response of onion to nitrogen fertilizer

Onion, compared with most crops, is usually the weakest crop plant in terms of extracting nutrients, especially the immobile types, because of their shallow and unbranched root system (Brewster, 1994). Thus, onion is a heavy feeder, requiring ample supplies of N; hence it requires and often responds well to addition of fertilizers. However, excess application of nitrogen causes excessive vegetative growth, delayed maturity, increase susceptibility to diseases, reduces dry matter contents and storability and ultimately reduces yield and quality of bulbs Brewster (1987), Sorensen and Grevsen (2001). The onion bulb size increased significantly with the application of different doses of nitrogen. Application of higher nitrogen of 120 kg ha^{-1} recorded the maximum bulb size while the minimum bulb size was recorded in control (Jilani *et al.,* 2009). Nitrogen significantly affected yields of various onion bulb size categories. Onion fertilized with different N levels decreased the yield of small sized bulbs, but increased the yield of large sized bulbs. Small sized bulbs decreased by 61.8% when N application was increased from 0 to 138 kg ha^{-1}. On the hand, when N fertilization increased from 0 to 138 kg ha^{-1} the increased large size bulbs increased from 12.58 t ha^{-1}to 25.67 t ha^{-1}, respectively, resulting in 104% increment (Negash *et al*., 2009).

Bolting is triggered in response to exposure of the onion plant to conditions like low or limited N supply which induces flowers to emerge before bulb are adequately grown to suppress flower initiation (Yamasaki and Tanaka, 2005). According to Abdissa et al. (2011), nitrogen fertilization significantly reduced bolting in onion. They also reported that, ratio of bolting percentage per plot decreased by about 11 and 22% in response to the fertilization of 69 and 92 kg N ha^{-1}, respectively as compared to the control.

The delay in maturity of onion bulb due to application of enhanced level of nitrogen. Generally, considering the status of the soil, additional nitrogen fertilizer levels application may be necessary in order to meet the crop N requirements (Meena et al,2007). Increasing nitrogen application rates significantly enhances plant height, number of leaves per plant and weight of bulb, marketable yield and also, total soluble solids as well as pungency (Nasreen et al., 2007; Al-Fraihat,2009) and (Randle ,2000 and coolong,.2003).

2.5. Response of onion to effect of plant density on yield and yield components

Plant density the number of individual plants present per unit of ground area. Plant spacing is also an important factor determining onion yield and quality. In crop production, canopy development is very important to optimize light interception, photosynthesis and dry matter accumulation to harvestable parts. So, crop canopy can be managed by alternating row spacing and plant population; as the plant density increases, yield per unit area also increases (Silvertooth, 2001).

Plant which has been grown too close together are competing for sunlight, essential nutrients, water, and air that leads to producing small bulb with a low quality and gave the maximum total yield of onions due to the presence of more plants, resulting in the highest total yield. But the size of the bulb under the closest spacing was so small that they were not suitable for marketing due to consume choice whereas a plant which has grown wider spacing produces vigor individual plant but low yield with high quality per given areas due to the presence of low plants and less competing for essential nutrients, water, sun light and air. the bulb under the wider spacing was so large that they were suitable for marketing due to consumer choice.

According to Dorcas et al. (2012), with increasing plant density of onion from lower 100,000 plants ha-1 to higher plant density of 500,000 plants ha-1 then average bulb weight and bulb diameter decreases from 58.22 g to 40.04 g and 4.56 cm to 2.83 cm. similarly, decrease in bulb neck diameter, mean bulb weight, plant height as the plant population per square meter increased from 50 to 200 plants likely due to competition associated with closely spaced plants that resulted in lower bulb weight per plant Kantona et al. (2003).

The smaller the marketable size is an issue for high plant densities and needs to be improved. According to Nasir et al. (2007) and Dawar et al. (2007), maximum weight of small and medium sized of onion was obtained at higher population density, However, the highest weights of large bulbs were found at the lowest planting density. Similarly. Rumpel et al. (2000), yield of medium bulbs increased with density but, the yield of large bulbs decreased as plant density increased. In addition, Stoffella (1996) also mentioned that percentage of small and medium sized bulbs increased and percentage of large bulbs decreased as intra-row spacing decreased. According to Coleo et al. (1996),the highest commercial bulb yield was recorded at a higher planting density, but the highest proportion of large bulbs and average bulb weight at lower planting density. Sufficient spacing between plants and rows and optimum amount N fertilizer application is vital to get highest yield in a given plot land (AVRDC 2004).

2.6. Response of onion to interaction effect of nitrogen and plant density

According to Islam et al. (1999), interaction effect of plant spacing and N levels on bulb yield of onion and most of the characters. The highest mean bulb weight was produced by the plants treated with higher nitrogen and lower population density. The increase in N fertilization level and plant population also resulted in the increase in yield from 3 to 10 t ha-^{1} Shojaei et al. (2011).

The highest bulb yield was recorded with treatment interaction of closer spacing (15 x 10 cm) and higher levels of nitrogen (150 kg ha-^{1}). The bulb diameter was highest in the wider spaced crop (15 x 20 cm) followed by 15 x 15 cm than narrow spacing. Similarly, increase nitrogen application rate significantly enhance plant height, number of green leaves per plant, weight of bulb and marketable yield. In addition to plant spacing is an important factor determining onion yield and quality (Nasreen et al.2007 and AL fraihat,2009).

Interaction effect of different intra-row spacing (10, 15, 20 and 25 cm) and levels of nitrogen fertilizer (0, 50, 100 and 150 kg N ha-^{1}) showed that an increase in nitrogen dose up to 100 kg ha-^{1} resulted in the increase of yield of onion bulbs 40.83 t ha-^{1} by interacting with 15 cm intra row spacing. But, further increase in N level up to 150 kg ha-^{1} did not significantly increase in bulb yield. The lowest bulb yield was recorded from the control plots when interacted with wider intra-row spacing of 25 cm (Aliyu et al, 2008). They also reported that, that treatment combinations of 0 kg N ha-^{1} and 10 cm intra-row spacing gave lower values of average bulb weight, bulb diameter and leaves number per plant.

2.7. Effect of weed on growth and yield of onion

Weed is defined as any plant growing where it is not wanted. This definition can apply to crops, native plants as well as non-native species. If it is considered to be a nuisance where it is growing, it can be termed a weed. However, weeds are not just unwanted species; they can have substantial negative impacts when they are present. Weeds can effectively compete with crop species, can lower yields, increase labor requirements and, ultimately, increase food costs for the consumer (Klingman and Ashton, 1975). Impact of weeds extends beyond economics to the environment as well, leading to soil erosion and degradation, and reducing biodiversity by outcompeting native species. Some weeds also pose hazards to human and animal health (Vishnu et al., 2023).

Weed is a plant that does more harm than good and has a habit of encroaching crop production. Onions do not compete well with weeds. They are slow growing and can suffer from successive flush of weed. They have narrow upright leaves which do not shade out weeds that emerge in the row. So, early season weed control is essential for successful crop production (M. Dhananivetha.et.al, 2016). The reduction in crop yield has direct correlation with weed competition. Onion exhibits greater susceptibility to weed competition as compared to other crops due to its inherent characteristics such as their slow growth, small stature, shallow roots and lack of dense foliage. The effective weed control involves identification of weed flora, method of weed control and judicious combination of effective weed control methods (M. Dhananivetha.et.al, 2016).

Weed causes a serious effect on the size of onion yields and it is identified as a major bottle neck in vegetable crop production next to diseases and insect pests (Lemma and Shimeles, 2003; Haile et al., 2016). Weed compete with onion for light, nutrient, water, space and also act as host plant of several harmful insects and pathogens and considerably reduce the yield, quality and value of the crop through increased production and harvesting costs (Uygur et al,2010).

According to Singh and Singh (1994), effect of weeds on crop growth components of onion un weeded onion reduced plant height, number of leaves, which in turn reduced the bulb diameter and bulb yield due to increased weed competition. James and Harlen (2010), indicated that uncontrolled weed growth caused 49-86 percent reduction in onion bulb yield compared with the best herbicidal treatment. The critical period of crop-weed competition in onion lies between 15-60 days after transplanting. Hence, managing the weeds meticulously in early stages is an imperative task to get higher weed control efficiency and bulb yield.

Weeds reduce crop yield because they compete with the crop plants for nutrients, water and light. In addition, weed also hinder with the crops harvesting and increase the cost of production **(**Khatam et al,2012). The reduction in bulb yield varies to the extent of 48 to 85 % depending upon the duration, intensity of weed growth and weed competition (Bhalla, 1978).

As a result, weed interference has reduced onion yield up to 40 to 80% in the world (Patel et al., 1983; Khatam et al., 2012) and 68 to 73% in Ethiopia (Etageneghu and Ahemed, 1985; Lemma and Shimeles, 2003; Grief, 2015) of the total production of onion.

Weed management is essential for onion production, because of the unique challenges posed by their planting densities and susceptibility to weed competition. Planting densities for onion pose unique challenges to weed management. These crops are slow growing and shallow rooted, planted at high densities, and susceptible to severe yield loss from weed competition. Their narrow, upright leaves do not compete well with weeds, and their long growing season allows for successive flushes of weed (https://www2.ipm.ucanr.edu/agriculture/onion-and-garlic/Integrated-Weed-Management/).

Importance of proper and timely weed management, Weeds directly compete with plants for growth factors like sunlight, water, nutrients, space, and this makes the crop weak and susceptible to attack by pathogens. They greatly reduce crop yield as well as its general performance, harbor pests and diseases. Some are parasitic while others are harmful when eaten by livestock and humans. Some weeds can damage the crop by producing toxic substances, and cause harvesting problems, especially those that develop late in the crop season. Timely weed management helps in protecting the yield potential of the crop by eliminating competition, protects the palatability and nutritional potential of the crop, and substantially curtails opportunities for pests' establishment in the crop.

Weeds can be controlled by different weed control methods such as manual, cultural, chemical, mechanical and biological. Usually, farmers do not remove weeds early enough to prevent major damage due to weed competition. Emphasis must be placed on techniques that reduce weed pressure before planting, such as the use of the stale seedbed method, weed-free seed, or soil solarization. Any method that reduces the amount of weed seed in the soil will reduce weeding costs during crop production. Weeds compete with the onion plants for nutrients and moisture during the growing season. Remove all weeds and grass by diligent and repeated shallow cultivation and hoeing. Side-dressing with fertilizer may be necessary.

2.8. Onion bulb initiation and formation

Bulb formation is a plant survival mechanism with factors such as weed competition and water stress triggering initiation (Brewster, 1990). Weed or neighboring onion canopy cover absorbs light from a certain wavelength, affecting the ratio of red to far-red light; the lower this ratio, the faster the bulbing rate. This ratio decreases when light passes through the canopy, as leaves absorb the red wavelength more readily than the far-red spectrum. Thus, a greater leaf area index and competing weeds will accelerate bulbing (Mondal et al., 1986). According to Heath and Hollies (1965), the initiation of bulb can be estimated by different measurements by destructive and nondestructive. bulbing has started as the development of leaf initials in to bladeless bulb scales. The measurement contributes to general understanding of factors controlling bulbing and flower production of onion. The estimation is expressed as bulbing ratio (maximum bulb diameter: neck diameter). Bulbing ratios greater than two commonly used as indicator that bulb initiation. Similarly, Abdella and Mann (1963) said that the reciprocal measurement, neck diameter divided by bulb diameter was also used by a ratio of 0.4 indicated that onset of bulbing.

2.8.1. Bulb maturity of onion crop

Time of bulbing and maturity has great concern in onion production The fall down of onion leaf helps to determine harvesting time according to the purpose of a producer. Similarly, Mondal *et al*. (1986) said that onion bulb reaches maturity when 80 % of foliage being falls down. In that harvesting is done considering different alternatives and the decision when to harvest is usually an economic concern. As the onion matures, food reserves begin to accumulate in the leaf bases and the bulb of the onion swells. The leaf is produced from the moistened apex (Abubakar et al,2010).

The grower may use to sell as green immature bulb or may be left in the field until it completely mature, that is waits to fully dormant to maximize recovery of assimilates from the leaves. However, in practice onion bulb is mostly harvested when the leaves of 50-70 % of the population have fallen over and indicated maturity (Currah and Proctor, 1990). They also reported that, Nitrogen affects maturity days, N prolongs maturity time. On contrary, Sorensen and Grevsen (2001), onion grown at low N supply the harvest time was postponed and the yield was reduced. A surplus supply of nitrogen did neither influence the harvest time nor the yield. In contrast, drought stress during the final growth forced the onions to mature. This effect reduced the yield and increased the dry matter percentage of the bulbs. Sprouting was postponed if plants had been grown at low N supply Sorensen and Grevsen (2001).

2.8.2. Bulb size distribution of marketable bulb yield

The marketable product is typically depending on onion cultivar (Dessalegne and Aklilu, 2003). According to them marketable bulb weight can be grouped into different size categories. These large (100-160 g), medium (50-85 g), and small (21-50g). oversized (above 160 g) These sizes can be preferred by consumers according to their purpose such as planting material, food, and for processing. According to EARO (2004), stated that the different bulb size category was indicated for different varieties under the Ethiopian conditions: Bombay Red (85-100 g), Adama Red (60-80 g), Red Creol (80-100 g), Melkam (70-90 g), and Dereselign (85-100 g). This showed that bulb size category is also highly dependable on variety in addition to intra-row spacing. With regard to unmarketable bulb yield of onion, it is related to the under sized bulb which is below 20 grams, diseased, decayed, physiological disorder such as thick necked, splits and bolters. Disorders are influenced by location, season, cultivar, and management practice. On the other hand, thick necked also occurs mainly when some of the proportion of bulbs fail to complete bulbing in which the leaves continue growing. Under this condition, the neck does not get soften and the bulb does not become dormant. Excess and continuous watering and late application of nitrogen contribute to this disorder (Lemma and Shimeles, 2003). They also revealed the cause splitting; bolting as well as larger sizes might be resulted when it in cool season. on other hand water shortages induced during the growth and bulbing stages led to higher percentages of small-size bulbs (Martin d*et al*., 2004).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

The experiment was conducted under irrigation in 2024 at Mekelle University, Arid Campus research site, which is located within the periphery of the city of Mekelle, capital of Tigray Regional state (Figure 1). The site is situated at 13^{0} 28' 47'' N latitude and 39^{0} 29' 10''E longitudes with an elevation of 2218 m.a.s.l. (Negash et al, 2009). The experimental site has a characteristic climate with an average minimum and maximum temperatures of 12^{0}C and 27^{0}C, respectively, The site also experiences a relative humidity 54%, daily sunshine hours 8.7 hours, wind speed of 2.4 m/s and receives mean annual rainfall of 530 mm.

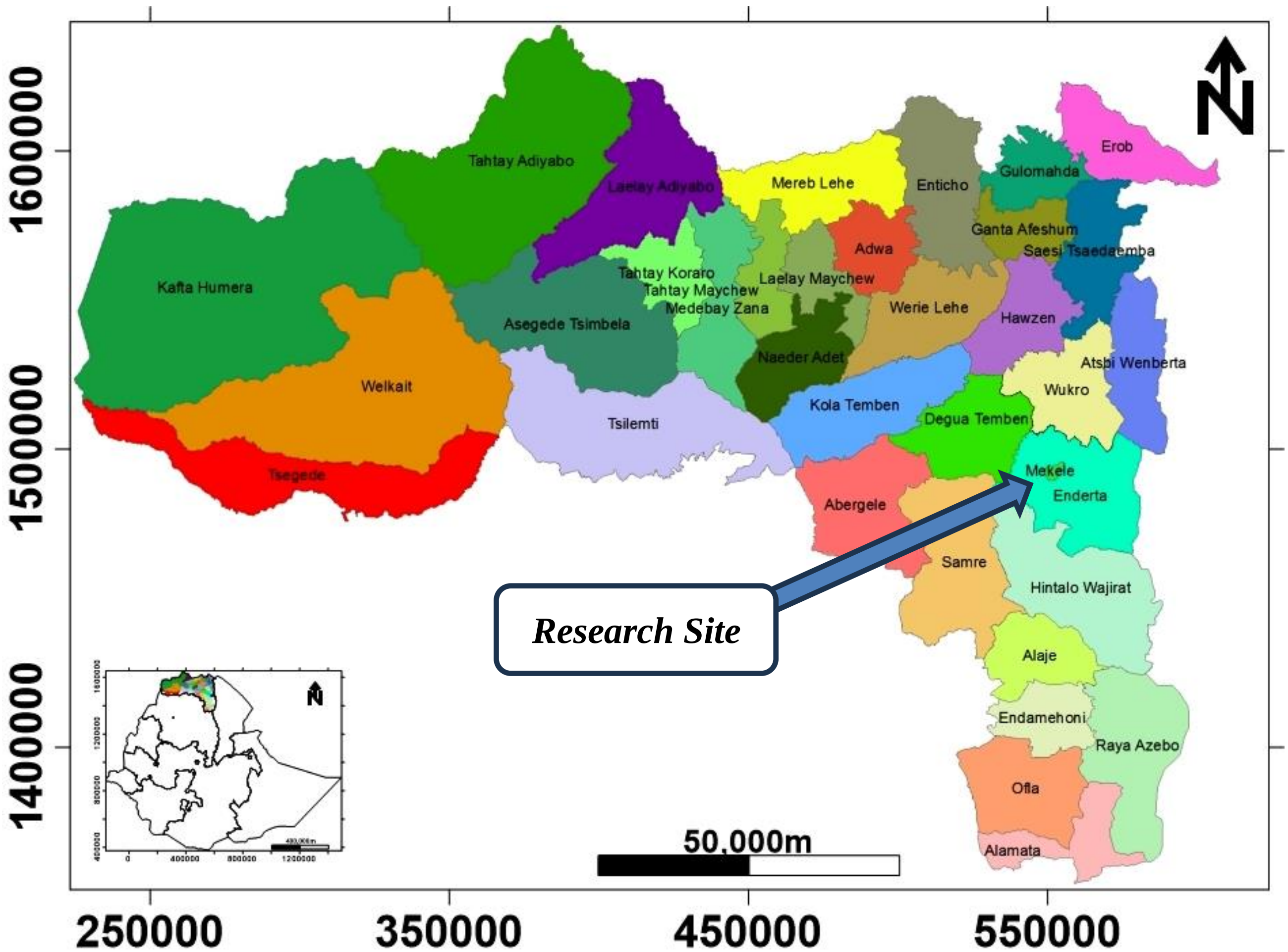

Figure 1. Location map of the experimental site

3.2. Experimental design and field lay out

A split plot design with three replications was used. The main plot was assigned for hand weeding (with and without) and the sub plots were for the combination of the four rates of N- fertilizer (0kgN/ha (control), 23kg N/ha, 46kg N/ha (recommended) and 69 kg N/ha) and three plant density levels: 222,222 plants/ha (P1), 333,333 plants/ha (P2) and 666,666 plants/ha (P3) that accounts 24 treatments The spacing between rows and plants for the three plant density levels were, respectively 30cm x 15cm, 30cm x 10cm and 30cm x 5cm where the middle is the recommended spacing used in the region.

Onion, variety Bombay Red, was used at the recommended rate of 3.5 kg/ha. It was released by Melkassa Agricultural Research Center in 1980 (EARO, 2004). The variety has light red bulb skin color, dark green leaf color, light pungent, flat globe bulb shape with bulb size of 85-100 cm, reddish white bulb flesh color and can mature in 100 - 120 days after transplanting with a yield potential of 30 t/ha. (EARO, 2004). It is also an excellent and very popular red onion used by farmers with very high market demand, highly adaptable and widely grown variety with excellent shelf life and transportability (www.ehniga.org, agroduka.com).

The onion seeds were sown in a nursery on well-prepared seed bed The seedlings were transplanted to the experimental field at 3 or 4 leaves stage with an estimated height of 12 to 15 cm. The main filed was prepared following the recommended tillage practice for the crop. A 2 m by 1.8 m (3.6m^2) plot size was prepared for each experimental unit. The distances between subplots, main plots and blocks were 1 m, 1m, and 1.5, respectively. Each treatment combination was assigned randomly to experimental units within a block. Each experimental plot had six single rows. Triple Super Phosphate (TSP) was used as source of P applied uniformly to all plots at nationally recommended rate of 92% P_2O_5. Urea was used as a source of N; first half of the N dose was applied after seedling establishment and the remaining half was side-dressed 45 days after transplanting.

During transplanting, uniform field management practices such as land preparation, P fertilizer, irrigation, pest and disease managements and harvesting was carried out for all plots as per the national agronomic recommendations for onion. After transplanting, three times full irrigation at three days interval was applied uniformly to all plots in order to ensure good plant establishment. Immediately after crop establishment, plants were irrigated based on crop water requirement and at the soils' field capacity depending on the moisture condition of the soil. Three days interval was maintained until two weeks days to harvest. Onion required 350mm up to 550mm of water to produce an optimal yield (https://www.fao.org). Irrigation was terminated two weeks before harvesting to strengthen bulb maturity. Samples for weed parameters (weed species identification, weed density, weed dry weight) was taken from each plot using a quadrate (25cm x 25cm) and recorded two times. First data at 30 days after transplanting and second at 60 days after transplanting. Weed cover was taken by recording percentage of an area occupied by weeds in a plot. Similarly, weed specimen were taken from each plot of the experiment using 25cm x 25cm quadrate, pressed and taken to weed laboratory for identification.

The crop was harvested when 90% of the leaves turned yellow and top fall, which are indicators for attaining full size of bulbs (physiological maturity) and then cured for 5 days (EIAR,2007). For data collection, the middle four single rows were considered excluding the two border rows as well as those plants at both ends of each row to avoid border effects. Sample for weed dry weight was taken during hand weeding and for crop dry weight was recorded after harvesting by drying plant samples in an oven for 24 hours at 65^0c (Elvis weullow,2020).

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3.3. Soil sampling and analysis

Soil samples were collected randomly from the entire experimental field following in a zigzag way from 0 to 20 cm and 20 to 40cm depth before planting and was made one kg composite sample. The composite soil sample was air dried, crushed with wooden pestle and mortar to pass through a 2 mm sieve size for the analysis of physical and chemical properties Soil analysis was made at Mekelle University soil laboratory following the standard procedures. Determinations of some selected soil physio-chemical properties like total nitrogen, Organic matter, soil PH, organic carbon, available phosphorus, potassium, cation exchange capacity (CEC) and soil texture were determined in the laboratory.

Soil pH was measured in 1:2.5 soil-water ratios using an electrodes pH meter determined by Jackson (1958). Organic carbon content of the soil was determined by Walkley and Black method (Walkley and Black, 1934). Total nitrogen was estimated by the Kjeldahl method (Jackson, 1958). Particle size distribution or soil texture was determined using hydrometer method. The results of the soil analysis were used as inputs in determining the applied amount of nitrogen fertilizer and to know the suitability of the selected site for onion production during experimental period.

3.4. Data collection and measurement

3.4.1 Weed data parameters

- **Weed identification:** weed species specimens were taken from each plot of the experiment using 25cm X 25cm quadrate. The weed species specimens were then pressed and taken to weed laboratory at MU for identification. The specimens were then checked against known species using a weed identification guide for Ethiopia (Ann and Chris, 1989) and their families, genus and species were identified.
- **Weed density per square meter:** this refers to the numbers of a weed plant per square meter and was recorded using 25cm X 25cm quadrate from each plot.
- **Weed dry weight (g):** this refers to the dry weight of a weed plant per square meter and was recorded using 25cm X 25cm quadrate from each plot.
- **Weed cover (percentage):** it refers to the percentage of the plot area covered by weed species. It was measured two times subjectively by observing the plot for the species covered by weed species.
- **Weed species composition, frequency, abundance and dominance:** Weed species composition and importance were analysed using frequency (F), abundance (A), dominance (D), and similarity index (SI) (Jaccard 1912; Taye & Yohanes 1998; Esayas et al. 2012; Assefa et al. 2016).

Frequency or prevalence: Percentage of sampling plots on which a particular weed species is found. It describes how often a particular weed species occurs in the survey area. Frequency is calculated for all weed species as follows:

Frequency: $F = X/N \times 100$

Where, F = frequency,

X = number of occurrences of a weed species,

N = sample number.

Abundance: Population density of a weed species expressed as the number of individuals of weed plants per unit area.

Abundance: $A = \Sigma W/N$

Where, A = abundance,

W = number of individual weed species,

N = sample number.

Dominance: Abundance of an individual weed species in relation to the total weed abundance i.e. infestation level.

Dominance: D = A/ΣAx100

Where, D = dominance,

3.4.2 Crop phenology

- **Days to 90% bulb maturity (day):** The number of days from seedling transplanting to a day at which more than 90% of the plants in a plot showed yellowing of leaves or attained physiological maturity.

3.4.3 Growth parameters

- **Number of leaves per plant;** the total number of leaves per plant was counted from five sample plants per plot randomly selected at physiological maturity.
- **Leaf length (cm);** This was measured at physiological maturity from the sheath to tip of the leaf from the five leaves of the representative plants, which were used to count the number of leaves per plant using a ruler.
- **Leaf diameter(cm);** The diameter of leaves at three different places of the leaves was measured from five randomly selected plants using veneer calliper.
- **Plant height (cm):** This was measured from the ground level up to the tip of the longest leaf using ruler. Plant height of five randomly selected plants were measured in the central rows of each plot at physiological maturity of the crop
- **Root length (cm);** This was measured at physiological maturity from the sheath to bottom of the root from the five leaves of the representative plants which was used to count the number of leaves per plant using a ruler**.**

3.4.4 Yield and yield component

- **Bulb weight (g):** The fresh weight of five randomly taken mature bulbs from plot measured using sensitive balance.
- **Bulb length (cm):** The height of five randomly taken mature bulb from plot measured by using ruler.
- **Bulb diameter (cm):** The bulb diameter of five sample bulbs was measured at the maximum wider portion of matured bulbs using calliper.
- **Neck diameter (cm):** The neck widths of five randomly taken mature bulbs was measured by using a veneer calliper.
- **Marketable bulb yield (kg/ha):** This referred to the weight of healthy and marketable bulbs that range from 20 g to 160 g in weight. Bulbs below 20 g in weight were considered too small to be marketed whereas those above 160 g were considered oversized according to Lemma and Shimeles (2003). This parameter was determined from the net plot at final harvest.
- **Unmarketable bulb yield (kg/ha):** The total weight of unmarketable bulbs that are under sized (< 20 g), diseased, decayed and bulbs from plants with physiological disorder such as thick neck and split was measured from a net plot at final harvest.
- **Total bulb yield (kg/ha):** The total bulb yield was measured as a sum weight of marketable and unmarketable yields that was measured in kg per plot and finally converted into kg/ha.
- **Bulb dry weight (g):** fresh bulbs were taken from each plot and weighed, and then dried in oven at 65^{O} C for 24 hours to constant weight (Elvis weullow,2020).

3.4.5 Quality parameters:

- **Total Soluble Solid content (**^{0}Brix**):** The TSS was determined at harvesting time from five randomly selected bulbs using the procedures described by Waskar *et al*. (1999). Aliquot juice was extracted using a juice extractor and 50 ml of the slurry centrifuged for 15 minutes. The TSS was determined by a hand refractometer (ATAGO TC-1E) with a range of 0 to 32 ^{0}Brix and resolutions of 0.20 Brix by placing 1 to 2 drops of clear juice on the prism.
- **Bulb shape index:** The mean bulb shape index was calculated by dividing the mean polar diameter by the mean equatorial diameter of the bulb. Bulb height was measured from the base of the neck to the root plate of an onion bulb. Bulb diameter is measured at the widest part of the bulb perpendicular to the neck/root axis. According to king et al. (1990), acceptable

onion bulb shape has an index up to 1.2 but onion with a bulb shape index more than 1.2 is considered as unacceptable for marketing.

3.4.6 Partial budget analysis

Partial budget as described by CIMMYT (1998) was analyzed by considering yield of onion in order to assess the costs and benefits associated with different factors (hand weeding, N rate and plant density). Economic analysis was done using the market price of inputs at weeding and planting, fertilizer cost and fertilizer application for onion yield. All costs and benefits were calculated on a kilogram per hectare basis in Ethiopian Birr. Onion yield was adjusted down by 10% to minimize the effect of researcher-managed small plots as compared to the farmers managed plots. Gross yield benefits, it is essential to know the field price value of one kg of onion bulb during harvesting time. Then finally, adjusted yield was multiplied by field price to obtain gross field benefit of onion. Dominance analysis is carried out by first listing the treatments in order of Increasing costs that vary. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that vary is dominated.

TGB = (AMY kg/ha) * (unit price Birr/kg) ………… ……………………… (Equation 1)

NB = (TGB) - (TVC)………………………………………………………… (Equation2)

MRR= (change in total income)/ (change in variable cost) ………………… (Equation 3)

Where, AMY= adjusted marketable yield, TGB= is the total gross benefit kg/ha, NB= is net benefit kg/ha for each treatment, TVC=total variable cost kg/ha for each treatment, MRR= is the marginal rate of return.

3.5 Data Analysis

The data were subjected to analysis of variance (ANOVA) using JMP 18 and GenStat version 16th edition. Treatments mean were compared using Honestly significant difference (Tukey HSD).test at 5% probability when treatment effects were significantly different at $p<0.05$. Correlation analysis was computed to generate information about the association of weed and other parameters.

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.4 Soil physical and chemical properties

The results of the soil physical and chemical properties are presented in Table 1. The result indicated that silt particles dominated the soil in both depths of 0-20 cm and 20-40 cm. The experimental area had a textural class of silt loam that possess about 58% and 52% silt, 18% and 17 % sand, 23.7% and 30.3% clay respectively for the soil depths 0-20 cm and 20-40 cm (Table 1).

The soil pH of the study area is moderately alkaline pH= (7.7) for the surface soil (0-20cm) and pH= (7.8) for the sub surface soil (20-40cm) as per classification of Tekalign (1991) (Table 1). According to Tekalign (1991), soil pH is classified as very strongly acidic (< 4.5), strongly acidic (4.5- 5.2), moderately acidic (5.3- 5.9), slightly acidic (6.0- 6.6), neutral (6.7- 7.3), and moderately alkaline (7.4- 8.0) and strongly alkaline (> 8.0). Optimum pH for onion production ranges between 6 and 8 (Nikus and Mulugeta, 2010). Accordingly, the pH of the soil was conducive for onion production.

The values of the total nitrogen (TN) of the soil before planting are 0.10 % and 0.11 %, respectively for the soil depths 0-20 and 20-40cm (Table 1). According to the soil analysis guide for onions by FAO (1983) and Landon (1991) rating, TN of the study area were rated as low respectively. This indicates the soils of the study area are deficient in N and need to be supplemented with high application of nitrogen to meet the crop nutrient requirement so as producing of high yield. Similarly, the P content of the experimental site was 5.5 ppm for the surface soil and 5.63 ppm for the sub surface soil.

According to the soil analysis guide for onions by FAO (1983) and Landon (1991), the total nitrogen (N) content should exceed 0.5 %, and the available phosphorus (P) value should be greater than 15 ppm. Similarly, Havlin et al, (1999) ranked soils with total N less than 0.2 as low. Depending on these scales, This also indicates that the P nutrient was below the optimum that demands application of high amount of P containing fertilizers.

The organic carbon (OC %) content of the experimental soil was 2.6 % in the depth of 0-20 cm and 2.4 % in 20-40 cm, which are rated as low and very low, respectively based on the rating by Bremner and Mulvaney (1987). They also reported that the OC% of soils are grouped as very high (> 20), high (10 to 20), medium (4 to 10), low (2 to 4) and very low (<2). Low OC content of the soil could also be contributed to the low soil total N content.

In addition, result of the soil analysis on organic matter (OM%) content of the experimental are was 4.4% in 0-20 cm and 4.1% in 20-40 cm soil depth, Based on Landon (1991), the organic content of the experimental are is regarded as medium. The cation exchange capacity (CEC) is an important parameter of soil; which describes the property of the fertility of soil. The Soil before planting was recorded 35.7 cmol (+) kg $^{-1}$ from a depth of 0-20 cm and 36.5 cmol (+) kg $^{-1}$ from the depth of 20-40cm (Table 1), which is considered very high. Based on the rating by Hazelton and Murphy (2007), soil with CEC values ranging from 25-40 cmol kg-1 is rated as high. Over all, there was no variation in pH, TN, P, OC, CEC and Bulk density, field capacity and permeant wilting point across the soil depth.

Table 1. Physicochemical properties of the experimental site before transplanting

Physical characteristics								
Soil depth	**B/D g/cm3**	**FC (cm)**	**PWP (cm)**	**Ava. Water (mm)**	**Particle size distribution (%)**			**Textural classification**
					Sand	**Silt**	**Clay**	
0-20cm	1.26	24.4	13.13	113.11	18.0	58.3	23.7	Silt Loam
20-40cm	1.29	25.5	13.31	121.71	17.7	52.0	30.3	Silt Loam

Chemical characteristics						
Soil depth	**pH**	**Total N (%)**	**AvailP (ppm)**	**OC (%)**	**OM (%)**	**CEC (cmol Kg-1)**
0-20cm	7.7	0.10	5.55	2.6	4.4	35.7
20-40cm	7.8	0.11	5.63	2.4	4.1	36.5

4.5 Identified Weed Species in Onion Fields

The number of weed species recorded in the study area is depicted in (Table 2). The result indicated that about 24 major weed species were identified in the experimental area. These identified weed species fell into 14 different families. The identified weed species comprised of annual (19 species) and perennial (5 species) in their life cycle and could also be categorized into broadleaf (23species), grasses (1 species) in their nature of growth habit. Out of the identified weed species, 95.8 % were classified a dicot and the rest was monocot 4.16 %. (Table 2).

Table 2 Weed species and their taxonomical characteristics in irrigated onion field at Mekelle University Research site in 2024 irrigation season.

Family name	scientific name of weed species	Common name	Life cycle	Group
Primulaceae	*Anagallis arvensis L*	Scarlet pimpernel	Annual	Dicot
Papaveraceae	*Argemone Mexicana L*	Mexican poppy	Annual	Dicot
Asteraceae	*Lanuaea capitata (spreng)Dandy*	Hazan, huwa	Annual	Dicot
Brassicaceae	*Sinapis arvensis L*	Wild mustard	Annual	Dicot
Brassicaceae	*Diplotaxis tenuifolia aislad (L) DC.*	Perennial wall- rocket	perennial	Dicot
Cucurbitaceae	*Cucurbita pepo L*	Summer squash	Annual	Dicot
Asteraceae	*Senecio inaequidens DC.*	South African ragwort	perennial	Dicot
Poaceae.	*Setaria pumila (poir.)Roem.&schuh*	Pigeon grass	Annual	Monocot
Sapindaceae	*Cardiospermum microcarpum Kunth*	Heart seed	Perennial	Dicot
Amaranthacea	*Amaranthus retroflexus L*	Red root pigweed	Annual	Dicot
Colchicaceae	*Colchicum alpinum DC.*	Alpine autumn crocus	Annual	Dicot
Asteraceae.	*Galinsogo parviflora Cav*	Guasca (Colombia)	Annual	Dicot
Asteraceae	*Xantinm strumarium L*	Cocklebur	Annual	Dicot
Fabaceae.	*Medicago polymorpha L*	California burclover	Annual	Dicot
Solanaceae	*Dature stramonium L*	Jimson weed	Annual	Dicot
Convolvulaceae	*Convolvvlus arvensis L*	Field bindweed	perennial	Dicot
Fabaceae.	*Vicia sativa L*	Common vetch	Annual	Dicot
Solanaceae	*Physalis cinerascens (Dunal)hitchc*	Small flower ground cherry	Perennial	Dicot
Polygonaceae	*Polygonum aviculare L*	Prostrate knotweed	Annual	Dicot
Asteraceae	*Tagetes minuta L*	wild marigold	Annual	Dicot
Amaranthaceae	*Bassia scoparia (L.) A.J.Scott*	Burning bush, kochia	Annual	Dicot
Amaranthaceae	*Chenopediuum vulvaria L*	Notch weed,	Annual	Dicot
Fabaceae	*Lathyrus sativus L*	Grass pea	Annual	Dicot
Boraginaceae.	*Euploca strigosa (willd.) Diane and Hilger*	Heliotropium strigosum wild.	Annual	Dicot

4.6 Analysis of Weed Species Importance

The dominant weed species was Asteraceae with five species, followed by Fabaceae and Amaranthaceous each with three species (Table 3).

From the first data record, *Lanuaea capitata (spreng) Dandy*, *Anagallis arvensis L, Argemone Mexicana L, Galinsogo parviflora Cav, Setaria pumila (poir.) Roem.&schuh, Colchicum alpinum DC, Sinapis arvensis L, Diplotaxis tenuifolia aislad (L) DC.* were recorded as the most predominant species (Table 3). Based on weed frequency top five weed species was found such as Lanuaea capitata (spreng) Dandy, Sinapis arvensis L, Anagallis arvensis L Argemone Mexicana L *as well as Diplotaxis tenuifolia aislad (L) DC.* With value of 81.9,81.9,74.6.68,68 % (Table 3).

Based on Second data record, *Anagallis arvensis L, Setaria pumila (poir.) Roem and schuh, Lanuaea capitata (spreng)Dandy, Galinsogo parviflora Cav, Colchicum alpinum DC, Argemone Mexicana L* the most predominate weed species. Based on frequency top five weed species was found *Anagallis arvensis L, Setaria pumila (poir.) Roem and schuh, Lanuaea capitata (spreng)Dandy, Galinsogo parviflora Cav, Argemone Mexicana L and Colchicum alpinum DC* species with the value 73.6, 69.4. 63.8,52.7,44.4%. (Table 3).

Generally, the current result found that from the first data record weed species was found a wide range of broad leaved in nature of growth habit. However, on the second data recorded decrease the broad leaf weed species and increase the grass weed species in the nature growth habit. Most of the weed species identified in the present study was in line with Bekele et al. (2006), Sankar et al. (2015) and Terfa (2018) who reported that the weed species found in onion field were comprised of a wide range of annual, biennial and perennial in life cycle and broad leaved, grasses and sieges in nature of growth habit.

Table 3 Importance analysis of identified weed species

Scientific name of weed species	At first weeding Fr. (%)	Ab. (ratio)	Dom. (%)	Rank	At second weeding Fr. (%)	Ab. (ratio	Dom (%)	Rank
Anagallis arvensis L	76.4	38.9	14.4	2	73.6	30.4	18.2	1
Argemone mexicana L	68	31.1	11.5	3	44.4	15.3	9.2	6
Lanuaea capitata (spreng)Dandy	81.9	45.6	16	1	63.8	22	13.2	3
Sinapis arvensis L	81.9	20.2	7.5	7	15.3	3.33	2.1	9
Diplotaxis tenuifolia aislad (L) DC.	68	18	6.6	8	27.7	7.77	4.7	8
Cucurbita pepo L	8.33	1.3	0.5	16	6.9	1.33	0.79	13
Senecio inaequidens DC.	47.22	13.1	4.8	9	30.5	8.45	5.1	7
Setaria pumila (poir.)Roem.&schuh	59.72	24.4	9.02	5	69.4	27.5	16.5	2
Cardiospermum microcarpum Kunth	16.66	4.9	1.8	11	6.9	1.11	0.66	14
Amaranthus retroflexus L	27.77	7.6	2.8	10	8.3	1.55	0.93	12
Colchicum alpinum DC.	43	22.9	8.4	6	43	16.7	9.98	5
Galinsogo parviflora Cav	48.61	28.7	10.4	4	52.7	21.8	13.1	4
Xantinm strumarium L	6.94	3.3	1.2	13	1.4	0	0	16
Medicago polymorpha L	8.33	3.6	1.3	12	5.6	1.11	0.66	14
Dature stramonium L	1.38	0.2	0.08	20	1.4	0	0	16
Convolvvlus arvensis L	5.55	0.9	0.03	21	1.4	0.22	0.13	15
Vicia sativa L	9.72	1.8	0.66	15	1.4	0.22	0.13	15
Physalis cinerascens (Dunal)hitchc	12.5	2.2	0.82	14	15.3	2.88	1.73	10
Polygonum aviculare L	2.77	0.4	0.16	19	1.38	0.22	0.13	15
Tagetes minuta L	4.16	1.1	0.41	17	1.38	0	0	16
Bassia scoparia (L.) A.J.Scott	2.77	0.9	0.33	18	1.38	0	0	16
Chenopediuum vulvaria L	1.38	0	0	22	4.16	1..11	0.66	14
Lathyrus sativus L	1.38	0	0	22	11.1	2.22	1.33	11
Euploca strigosa (willd.) Diane and Hilger	1.38	0	0	22	8.33	1.33	0.79	13

N.B.: Fr = weed species frequency; Ab. = Weed species abundance; and Dom. = Weed species dominance. Rank is made based on dominance values

4.7 Hand weeding, N rate and plant density effects on weed parameter

4.7.2 Weed density

Hand weeding had significant ($p<0.05$) effect on weed density but such effect was not observed from N rate and planting density (Table 4). In addition, interaction effect of hand weeding and N rate showed significantly variation on weed density (Table 5). Nevertheless, the interaction effect of hand weeding and plant density and interaction effect of N rate and plant density did not show significant difference on weed density (Table 6 and 7). In addition, interaction effect of all factors did not show significant variation on this parameter (Fig 2).

The highest weed density was recorded from un weeded plots (211 weed plants/m^2) and the lowest weed density (123 weed plants/m^2) was from hand weeded plots (Table 1). This indicates that hand weeding reduced weed density by around 42%. In support of this result, Rahman et al. (2012), weeding and appropriate time of weed removal could significant effect weed infestation.

The interaction effect of hand weeding and N significantly difference in weed density. The highest (284 weed plants/m^2) weed density was recorded from un weeded plots received 0kg N ha^{-1} fertilizer and the lowest weed density (105 weed plants/m^2) was observed from hand weeded plots received N fertilizer 0kg N ha^{-1} (Table 5).

4.7.3 Weed dry weight

Hand weeding had significant effect on weed dry weight but such effect was not observed from N rate and plant density (Table 4). Additionally, interaction effect of hand weeding and N rate show significant variation on weed dry weight (Table 5). However, interaction of hand weeding and plant density and N rate and plant density did not result in significant difference of weed dry weight (Table 6 and 7). Similarly, interaction of all factors did not show significant effect on weed dry weight (Fig 2).

Weed plants with the highest dry weight (298g/m^2) was recorded from weedy plots and the lowest dry weight (217g/m^2) was recorded from hand weeded plots (Table 1). This means that hand weeding reduced weed dry weight by around 93% which implies that weeding reduced loss in farm resources (nutrients and water) to a larger amount and made it available to the crop. Indirectly, hand weeding can shift the competition advantage from the weed to the crop.

With regard to the interaction effect of hand weeding and N rate significantly variation in weed dry weight. The highest (369g/m^2) weed dry weight was recorded from un weeded plots received no N fertilizer (0kg N ha^{-1}) and the lowest weed dry weight (154g/m^2) was observed from hand weeded plots received no N fertilizer (0kg N ha^{-1}) and (23kg N ha-^{1}).

4.7.4 Weed cover

The analysis of variance indicated that hand weeding showed statistically significant ($p<0.05$) effect on weed cover but such effect was not observed from N rate and planting density (Table 4). However, the interaction of hand weeding and N rate, hand weeding and plant density as well as N rate and plant density did not show significant effect on weed cover. (Table 5, 6 and 7). Additionally, interaction of all factors did not show significant effect on this parameter (Fig 2).

The weed species covered to maximum of 61% in weedy plots considering the whole plot area rather than only the space occupied by the rows of onion plants. The lowest area percentage (21%) covered by weeds was in hand weeded plots (Table 4). Hand weeding reduced the weed coverage by 65.6%.

Table 4 Hand weeding, N rate and plant density effects on weed density, weed dry weight .and weed cover

Factor	**WD**	**WDW**	**WC**
Hand weeding			
with	123[b]	217[b]	21[b]
without	211[a]	298[a]	61[a]
S E (+)	42.3	35.53	30.89
P value	0.014	0.036	0.021
Significance	*	*	*
N (kg ha -1)			
0	195	262	44
23	154	236	43
46	159	270	41
69	160	262	42
S E (+)	30.18	53.28	8.097
P value	0.2831	0.9157	0.7707
Significance	ns	ns	ns
Planting density(no/m^2)			
P1	185	278	39
P2	158	244	43
P3	157	249	45
S E (+)	32.16	30.41	8.032
P value	0.2890	0.7057	0.0719
CV (%)	41.56	58.96	20.31
Significance	ns	ns	ns

Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1= 222,222 plants /ha, p2=333,333 plants/ha, p3=666,666 plants/ha, WD= weed density in weed plants/m^2, SE =WDW=weed dry weight in g/m^2, WC=weed cover in %, standard error, CV= coefficient of variation, p value =probability

Table 5 Interaction effects of hand weeding and N rate on Weed Density, Weed Dry weight and Weed Cover

N rate (kg/ha)	**WD**		**WDW**		**WC**	
	Hand weeding					
	with	**without**	**with**	**without**	**with**	**without**
0	105^{c}	284^{a}	154^{cd}	369^{a}	25	64
23	112^{c}	196^{b}	187^{c}	302^{ab}	25	61
46	140^{bc}	178^{b}	280^{b}	238^{bc}	24	59
69	133^{bc}	187^{ab}	225^{bc}	299^{ab}	23	61
SE (+)	46.84		47.39		11.17	
P value	0.0167		0.027		0.9058	
Significance	*		**		ns	

Means followed by the same letter within a column are not significantly different at 5% of significance. WD= weed density in weed plants/m^2, SE =WDW=weed dry weight in g/m^2, WC=weed cover in %, standard error, CV= coefficient of variation, p value =probability

Table 6 Interaction effect of hand weeding and Planting density on weed density, weed dry weight and weed cover

Plant density	**WD**		**WDW**		**WC**	
	Hand weeding					
	with	**without**	**with**	**without**	**with**	**without**
P1	136	179	203	354	22	57
P2	108	208	243	245	47	62
P3	124	247	205	294	26	65
SE (+)	45.391		50.4		11.08	
P value	0.1317		0.2431		0.7458	
Significance	ns		ns		ns	

Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1= 222,222 plants /ha, p2=333,333 plants/ha, p3=666,666 plants/ha, WD= weed density in weed plants/m^2, SE =WDW=weed dry weight in g/m^2, WC=weed cover in %, standard error, CV= coefficient of variation, p value =probability

Table 7 Interaction effect of N rate and Planting density on weed density, weed dry weight and weed cover

N rate (kg/ha)	**WD**			**WDW**			**WC**		
	Planting Density								
	P1	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**
0	251	171	163	334	223	228	45	44	44
23	165	144	152	294	226	188	38	45	46
46	184	139	155	253	320	237	41	39	45
69	141	179	160	232	208	346	34	46	47
SE (+)	40.441			61.654			8.5989		
P value	0.4546			0.3671			0.3772		
Significance	ns			ns			ns		

Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1= 222,222 plants /ha, p2=333,333 plants/ha, p3=666,666 plants/ha, WD= weed density in weed plants/m^2, SE =WDW=weed dry weight in g/m^2, WC=weed cover in %, standard error, CV= coefficient of variation, p value =probability

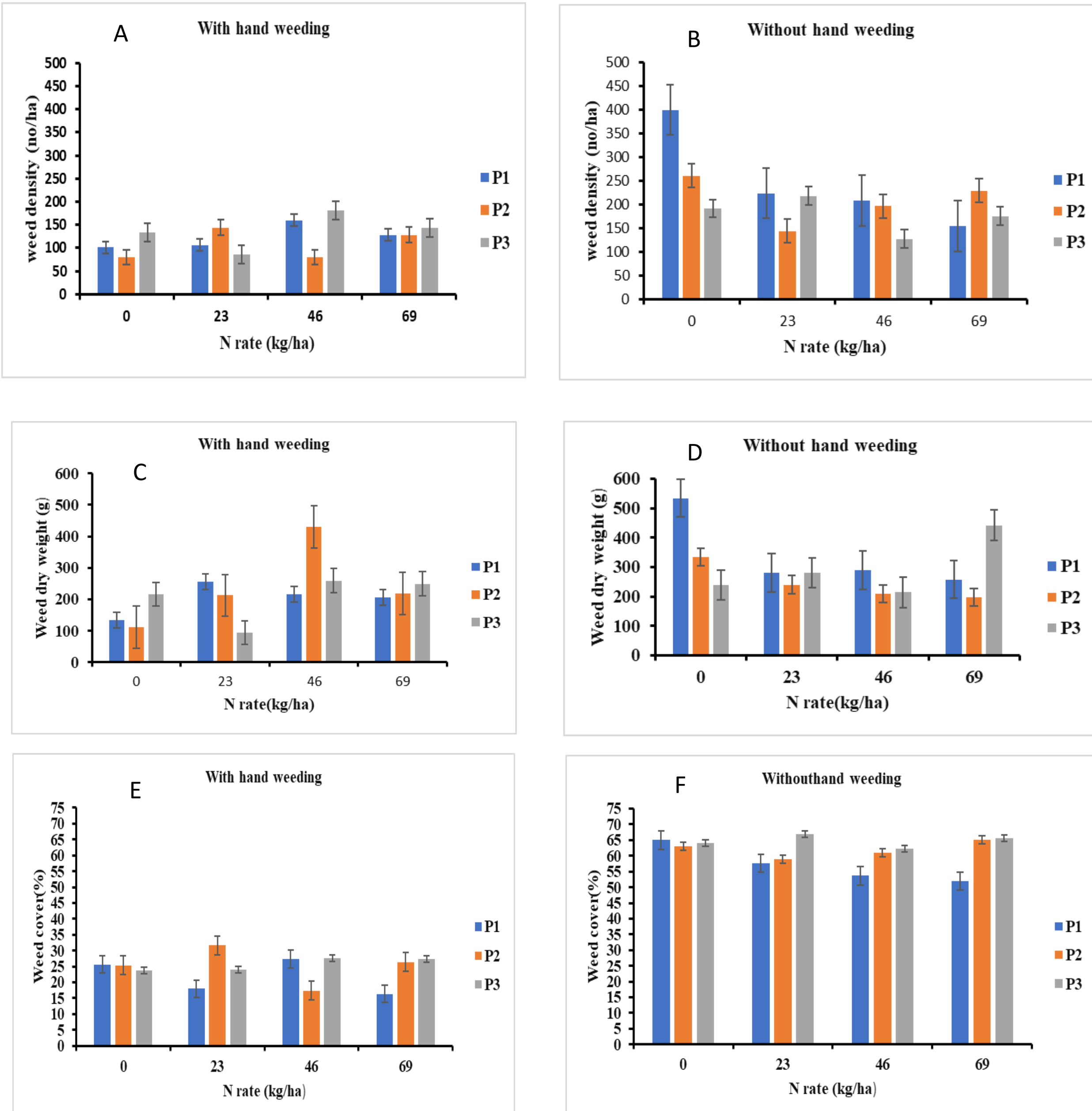

Figure 2 Interaction effects of all the factors on weed parameters of onion. AB= with and without hand weeding for weed density CD= with and without hand weeding for weed dry weight, EF=with and without hand weeding for weed cover, P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha

4.8 Hand weeding, N rate and plant density effect on crop Phenology

4.8.2 Days to 90% maturity

The result of the analysis of variance indicated that hand weeding and N rate significantly affected days to maturity (Table 8). Nevertheless, plant density and interaction of hand weeding and N rate, hand weeding and plant density as well as interaction of N rate and plant density did not reveal significant ($p < 0.05$) effect on days to maturity (Table 9,10 and 11). Likewise, interaction of all factors also did not show significant effect on this parameter (Fig 3).

Increasing the rate of nitrogen markedly prolonged the days to maturity of the onion crop (Table 8). Onion plants grown at 69 kg N ha-^{1} under weed free plot took the highest number of days (118.8days) to reach maturity. In contrast, the lowest number of days to reach maturity (113,114, and 114 days) was observed from onion plants grown at nil, 23kg N ha^{-1} and 46kg N ha^{-1} with no significant difference among each other. This, indicated that plants grown with higher rates of nitrogen application and kept weed-free take progressively longer to mature than plants that receive lower rates of nitrogen and are not weeded.

The delay in maturity in response to the increased rate of nitrogen application may be attributed to nitrogen enhancing plant biochemical processes, which in turn extends vegetative growth as a result of which it leads to delayed maturity (Brewester, 1994 and Marschner, 1995). In agreement with the result of this study, Brewster (1994) and Sørensen and Grevsen (2001), ample of nitrogen supply could result in excessive vegetative growth and delayed maturity of onion.

4.9 Hand weeding, N rate and plant density effect on growth parameters

Understanding and optimizing growth parameters is crucial as they critical factors that directly or indirectly influence crop yield. Therefore, this study considered leaf number, leaf diameter, plant height, and root length of onion to investigate their response to weeding, N rate and plant density.

4.9.2 Leaf number

Hand weeding had significant effect on leaf number but such effect was not observed from N rate and planting density (Table 8). In addition, interaction of hand weeding and N rate, hand weeding and plant density as well as N rate and plant density did not show significant effect on leaf number (Table 9,10 and 11). Similarly, interaction of all factors did not show significant effect on leaf number (Fig 3). This indicated that the factors had independent effect on leaf number. This means that hand weeding caused higher impact on onion leaf growth and development than N fertilizer and planting density.

Plants with the highest leaf number (9) was found in hand weeded plots and the lowest (6) was recorded from weedy plots. This means that weeds reduced leaf number by about 33%. Supporting the current study result, Singh (1994), number of onion leaves increased significantly in plots which were kept weed free till harvest due to least crop-weed competition for essential resources (nutrients, moisture, space and sunlight).

4.9.3 Leaf length

Hand weeding and plant density had significant effect on leaf length (Table 8). But N rate as well as the interaction of hand weeding and N rate, hand weeding and plant density and interaction of N rate and plant density did not show significant effect on leaf length (Table 9,10,11). Moreover, the three-factor interaction did not show any significant effect on leaf length (Fig 3). Onion had longer leaves (40 cm) in weed free plots than in not weeded plots (30 cm) (Table 8). The longer leaves in hand weeded plots might be attributed to the availability of enough essential resources to enhance vegetative growth of the crop in general. Similarly, onion with relatively longer leaves (33.7 cm) were observed in plots with a higher plant density of 666,666 /ha while the shortest leaves (30.7cm) were recorded from plots with lower plant densities (222,222 plants/ha). The longer leaf length in higher planting density might be in response to crop's competition to light as longer leaves intercept more light than shorter ones. However, in contrary to this result, Khan et al. (2003) and Khan et al. (2002), longer leaf length of onion varieties in a low planting density which might be due to more space between plants that can allow for more resources per plant and allows the leaf to grow robustly and enhances plant growth.

4.9.4 Leaf Diameter

Hand weeding had significant effect on leaf diameter, whereas not such effect was observed from N rate and planting density (Table 8). Additionally, leaf diameter did not show significant variation by interaction of hand weeding and N rate, hand weeding and plant density as well as N rate and plant density (Table 9,10 and 11). Likewise, interaction of all factor did not show significant effect on leaf diameter (Fig 3). Onion with wider leaf diameter (0.95 cm) was observed in hand weeded plots that might be linked to the longer leaves of onion in hand weeded plots. The least leaf diameter (0.8 cm) was observed in weedy plots which ultimately indicated that weeds resulted in significant effect on leaf growth of the crop. Both leaf length and leaf width determine the overall leaf area that influences the photosynthetic capacity of the crop.

4.9.5 Plant height

Like the other growth parameters, plant height had showed significant variation by weeding but not due to application of various N rates and planting density (Table 8). Besides, plant height did not show significant difference by interaction of hand weeding and N rate and hand weeding and plant density as well as interaction of N rate and plant density (Table 9,10 and 11). Moreover, the three factors interaction also did not show significantly effect on plant height (Fig 3). Onion crop with taller height (40 cm) was found from hand weeded plots (Table 8). This could be due to favorable environment in the root zone, which allows for efficient absorption of water and nutrients. Consequently, the less competition between the crop and weeds for resources leading to robust growth. These results are nearly identical to Priya et al. (2017), Jagadeesha et al. (2020) and Khan et al. (2021), weed free environment preserved growth inputs such as light, moisture, nutrients, and space, and improved the edaphic and nutritional conditions in the root zone, which in turn enhanced the onion plant height. Despite that, the shortest onion plants (33.5 cm) were found in un weeded plots. That means the height is influenced more by inter-specific than intra-specific competition. The non-significant effect of planting density on the height of the crop is similar with, Khan et al. (2002) report who found no change in onions plant height in wider spacing beyond 7.5 cm.

4.9.6 Root length

The analysis of variance revealed that root length of onion has not show statistical significance variation neither by the hand weeding nor by N rate and plant density (Table 8). Similarly, root length did not show significant variation by interaction of hand weeding and N rate and hand weeding and plant density as well as interaction of N rate and plant density (Table 9,10 and 11). Additionally, the root length was not significantly different by all interactions (Fig 3).

Table 8 Hand weeding, N rate and plant density *effects* on growth parameters of onion

Factors	DMAT	LN (no)	LG (cm)	LD (cm)	PLHT (cm)	RL (cm)
Hand weeding						
With	117.1[a]	9[a]	40[a]	0.95[a]	40[a]	8.53
Without	113.3[b]	6[b]	30[b]	0.8[b]	33.5[b]	6.9
S E (+)	0.8084	0.21	0.69	0.046	0.59	0.4626
P value	0.038	0.014	0.049	0.046	0.019	0.1369
Significance	*	*	*	*	*	ns
N (kg ha -1)						
0	113.3[b]	7.8	31.8	0.87	38.3	7.7
23	114.3[b]	7.2	32.9	0.96	36	7.7
46	114.8[b]	8	32.7	0.87	36.6	7.9
69	118.8[a]	7.5	30.5	0.82	35.9	7.6
S E (+)	0.79	0.26	1.01	0.062	0.914	0.441
P value	0.001	0.146	0.317	0.306	0.294	0.954
Significance	*	ns	ns	ns	ns	ns
Plant density(no/ha)						
P1	115.8	7	30.7[b]	0.80	36.1	7.5
P2	115.6	8	31.6[ab]	0.9	36.1	7.7
P3	114.6	7.7	33.7[a]	0.95	37.9	7.9
S E (+)	0.89	0.23	0.88	0.0570	0.7765	0.4029
P value	0.362	0.388	0.0458	0.0956	0.2940	0.6889
Significance	ns	ns	*	ns	ns	ns
CV (%)	2.73	14.29	13.15	25.85	11.14	19.96

* Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha DMAT=days to maturity LN= leaf number; LG= leaf length, LD= leaf diameter, PLHT=plant height, RL= root length SE =standard error, CV= coefficient of variation, p value =probability

Table 9 Interaction effect of *hand* weeding and N rate on growth parameters of onion

N rate (kg/ha)	DMAT		LN (no)		LG (cm)		LD (cm)		PLHT (cm)		RL (cm)	
	Hand weeding											
	with	without	with	without	with	without	with	without	with	without	with	without
0	114.8	112.0	9	6	33	31	1	0.8	41	35	8	7
23	115.4	113.2	8	7	36	30	1	0.9	39	33	9	7
46	117.2	112.6	10	7	36	30	1	0..75	41	33	9	7
69	121.0	116.8	9	6	31	30	0.9	0.8	39	33	8	7
S E (+)	1.216		0.3814		1.398		0.0796		1.322		0.641	
P value	0.6116		0.4539		0.4233		0.6334		79.39		0.9349	
Significance	ns		ns		ns		ns		ns		ns	

* Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha LN= leaf number (no. of leaves per plant; LG= leaf length in cm, LD= leaf diameter in cm, PLHT=plant height in cm, RL= root length in cm SE =standard error, P-value =probability

Table 10 Interaction effect of *hand* weeding and plants density on growth parameters of onion

Plant density	DMAT		LN		LG		LD		PLHT		RL	
	Hand weeding											
	With	Without	with	without	with	without	with	without	with	without	with	without
P1	117.2	114.5	9	6	33	28	0.9	0.7	40	33	9	7
P2	118.0	113.3	9	6	33	30	1.0	0.8	39	33	8.5	7
P3	116.2	113.1	8.9	7	35	32	1.0	0.9	41	35	8.6	7
S E (+)	1.097		0.33		1.21		0.0702		1.133		0.5876	
P value	0.5147		0.66		0.70		0.2263		0.79		0.7632	
Significance	ns		ns		ns		ns		ns		ns	

* Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha LN= leaf number (no. of leaves per plant; LG= leaf length in cm, LD= leaf diameter in cm, PLHT=plant height in cm, RL= root length in cm SE =standard error, P-value =probability

Table 11 Interaction effect of N *rates* and plants density on growth parameters of onion.

N rate (kg/ha)	DMAT			LN			LG			LD			PLHT			RL		
	Planting Density																	
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
0	113.2	113.7	113.3	8	8	8	32	31	33	0.9	0.9	0.9	39	37	39	7	8	8
23	114.3	114.8	113.8	7	8	7	33	33	33	0.9	0.8	1.0	37	36	34	7	8	8
46	116.3	114.3	114.0	7	8	9	32	32	35	0.9	0.8	0.9	35	36	39	9	7	8
69	119.5	119.8	117.3	7	8	7	26	31	35	0.6	0.8	1	34	35	39	8	7	8
S E (+)	1.4302			0.45			1.73			0.978			1.64			0.6766		
P value	0.8679			0.41			0.1911			0.4641			0.27			0.1977		
Significance	ns			ns			ns			ns			ns			ns		

* Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha LN= leaf number (no. of leaves per plant; LG= leaf length in cm, LD= leaf diameter in cm, PLHT=plant height in cm, RL= root length in cm SE =standard error, P-value =probability

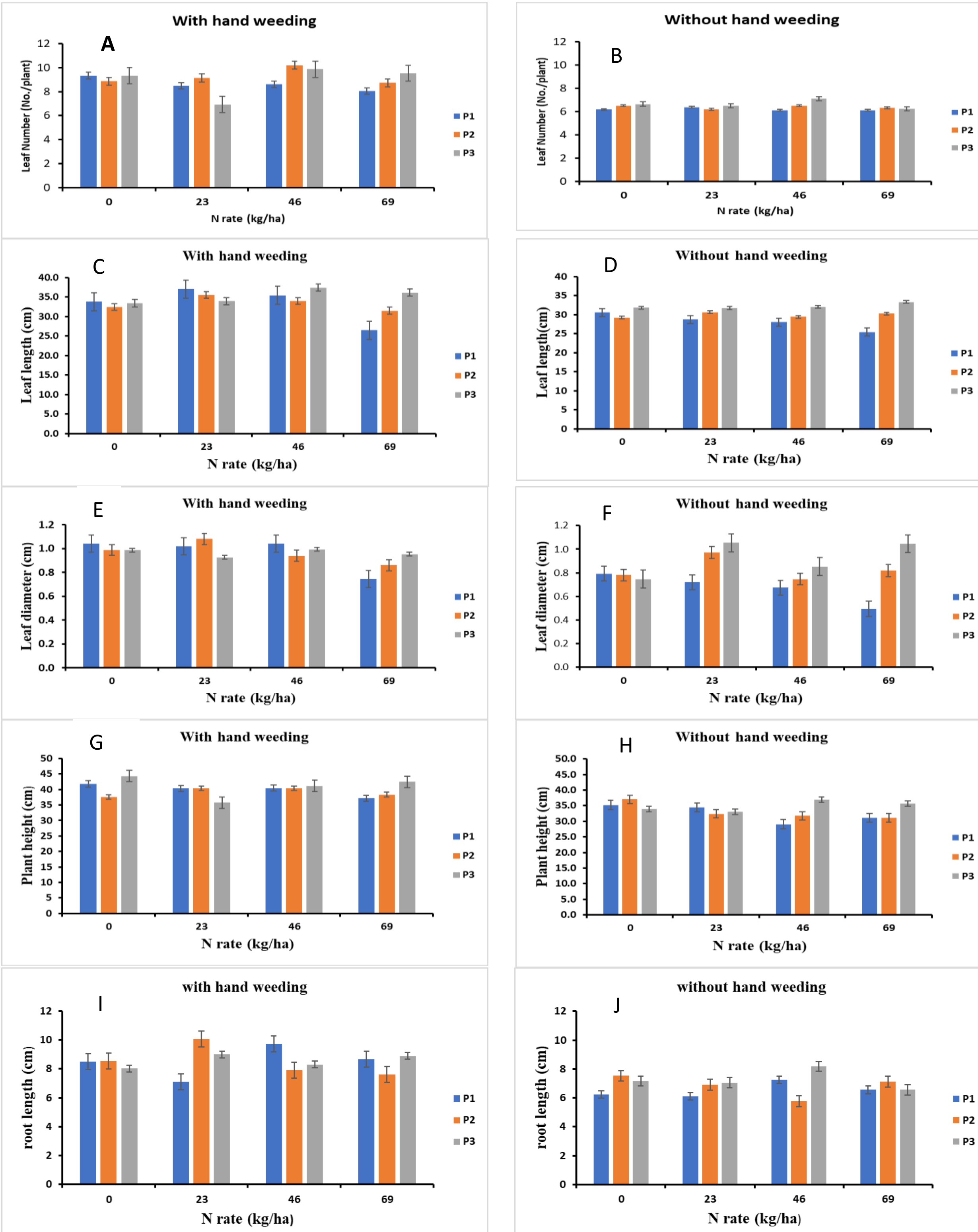

Figure 3 Interaction effects of all the factors on growth parameters of onion. AB= with and without hand weeding for leaf number, CD= with and without hand weeding for leaf length EF=with and without hand weeding for leaf diameter, GH= with and without for plant height= root length, P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha.

4.10 Hand weeding, N rate and plant density effect on yield component of onion

4.10.2 Bulb weight

Hand weeding and plant density had significant effect on bulb weight but such effect was not observed from N rate (Table 12). On the other hand, interaction of hand weeding and planting density show significant effect on bulb weight (Table 14). Nevertheless, interaction of hand weeding and N rate, N rate and plant density did not show significantly effect on this parameter (Tables 13 and 15). Additionally, bulb weight did not show Significant difference by three interaction (Fig 4). The highest bulb weight (59 g) was recorded on hand weeded plots but the least bulb weight (37g) was recorded from weedy plots (Table 12). The highest onion bulb weight from hand weeded plots might be due to the less inter-specific competition between onion and weed plants for adequate nutrient, moisture and light which in turn helped to increase the weight of bulb per plant

Increasing the planting density progressively increased the bulb weight of the onion plants Thus, the highest bulb weight (53.6 g) was found in response to the 666,666 plants ha^{-1} while the lowest bulb weight (44.8 g) was obtained from 222,222 plants ha-^{1} $^{(}$Table12). This result is inconsistent with the results of Muhammad *et al*. (2011), Mahadeen, (2008), Dorcas *et al*. (2012) and Jilani *et al*. (2010) found that the lowest bulb weight was obtained for high plant density spaced onion plants.

Similarly, The highest bulb weight (61 g) was recorded from hand weeded plots with 333,333 plants ha^{-1} and the lowest (31g) was from the un-weeded plots with the 333,333 plants ha^{-1} ^{1}(Table 14). This might be attributed due to the inter-specific and intra-specific competition of the crop with the weeds and within the onion plants, respectively, The former competition may suppress the onion plants and favor the weeds to grow and compete with the crop. According to Khan et al. (2002), wider spacing accommodated a smaller number of plants which received adequate nutrient, moisture and light which helped to increase the average weight of bulb per plant.

4.10.3 Bulb length

The analysis of variance revealed that bulb length had showed statistically significant ($p < 0.05$) effect by hand weeding and N rate (Table 12). Moreover, bulb length had showed significant variation by interaction of hand weeding and N rate (Table 13). However, interaction of hand weeding and plant density, N rate and plant density did not show significant effect on bulb length (Tables 14 and 15).

Additionally, the interaction of all factors did not show significantly effect on bulb length (Fig 4). The longest bulb (5 cm) was obtained from hand weeded plots whereas the shortest bulb (4.7 cm) was found from weedy plots. When observing at the effect of N rates, the longest bulb (5cm) was recorded in response to the application of 23 kg N/ha-^{1} and 46 kg N/ha-^{1} and the shortest bulb (4.7cm) was obtained from receiving 69 kg N/ha-^{1}.

The interaction of hand weeding and N rate significantly effects on bulb length. The longest bulb (5.3 cm) was recorded in response to the application of 46 kg N/ha-^{1} and the shortest bulb (4.7cm and 4.6 cm) was obtained from hand weeded and weedy plots receiving the highest rate (69 kg N /ha-^{1}) (Table 13). Generally, increasing the amount of nitrogen provided to onion consistently decrease the bulb length across the hand weeded plots.

4.10.4 Bulb diameter

Hand weeding and plant density had significant ($p < 0.05$) effect on bulb diameter but such effect was not observed from N rate (Table 12). In addition, bulb diameter had showed significant variation by interaction of hand weeding and plant density (Table 14). Besides, interaction of hand weeding and N rate as well as N rate and plant density did not show significant effect on bulb diameter (Tables 13 and 15). Likewise, the three factor interactions did not show significant effect on this parameter (Fig 4). The widest bulb diameter (4.6 cm) was recorded from hand weeded plots. The narrowest bulb diameter (3.75 cm) was obtained from un-weeded plots (Table 12). These results are supported by the findings of Singh and Singh (1994) un weeded onion plots recorded reduced bulb diameter due to increased weed competition for water, air and important nutrients.

Similarly, the widest bulb diameter (4.4 cm) was observed from the highest planting density (666,666 plants ha^{-1}) and the least (4.03 cm) was obtained from the lowest population density (222,222 plants ha^{-1}) with no significant difference with the plant population at 333, 333 plants ha^{-1}(Table 12).

With regard to the interaction of hand weeding and plant density, the wider bulb diameter (4.6 cm) was recorded from hand weeded plots with (333,333plantsha-^{1}) whereas the smallest bulb diameter (3.3 cm and 3.4 cm) was recorded from un-weeded plots from both 666,666 plantsha^{-1} and 333, 333 plants ha^{-1} with no significant statistical difference (Table 14). Consistent with the results of this study, Dorcas et al. (2012) with increasing plant density of onion from lower 100,000 plants ha^{-1} to higher plant density of 500,000 plants ha^{-1}, bulb diameter decreases from 4.56 cm to 2.83 cm.

4.10.5 Bulb neck diameter

Bulb neck diameter is one of the yield components of onion that determines the shape of the bulb, which has a significant role in marketability. Hand weeding had significant effect on bulb neck diameter but such effects was not observed from N rate, planting density (Table 12). However, Bulb neck diameter has showed significant variation by interaction of hand weeding and N rate as well as hand weeding and plant density (Table 13 and 14). But, interaction of N rate and plant density as well as all factors interaction did not show significant effect on bulb neck diameter (Table 15 and Fig 4).

Onion plants with the highest bulb neck diameter (0.50 cm) was obtained from hand weeded plots. and the lowest bulb neck diameter (0.36 cm) was recorded from weedy plots. (Table 12). This might be due to high competition among crop and weed for light, air and water that is more imperative for photosynthesis and nutrients associated with weedy plot.

The interaction of hand weeding and N rate had significant effect on bulb neck diameter. The highest neck diameter (0.64 cm) was recorded from hand weeded plots that received 46 kg N ha^{-1}but the lowest bulb diameter (0.17cm) was recorded from un-weeded plots that received the same N rate (Table 14). Jilani *et al*. (2004), reported that application of N at the rate of 200 kg $ha-^{1}$ increased the number of thick-necked bulbs. Similarly, KI Chanu et al. (2022), reported that application of higher amount of nitrogen enhances vegetative growth and accelerating the photosynthesis in plants, leading to translocation of photosynthates in storage organ of onion (bulb) resulting in an increased neck diameter.

With regard to the interaction effect of hand weeding and plant density, Onion bulbs with thicker necks (0.72 cm) were observed from hand weeded plots with the lowest plant density (222,222plants ha^{-1}) (Table 14). In line with this study, Khan *et al*. (2002), highest bulb neck diameter was observed at the low onion plant population and may be attributed to vigorous growth of the plants as a result of less stiff competition from weeds for growth resources. On the other hand, the narrow intra-row spacing with its high plant populations may have exerted pressure on scarce growth resources such as light, space, moisture and nutrients, leading to reduced growth and narrow bulb neck diameter.

Table 12 Hand weeding, N rate and Plant density effect on yield components of onion.

Factors	**BW**	**BL**	**BD**	**ND**
Hand weeding				
with	59^{a}	5^{a}	4.6^{a}	0.50^{a}
With out	37^{b}	4.7^{b}	3.75^{b}	0.36^{b}
S E (±)	1.44	0.03	0.04515	0.021
P value	0.0103	0.01	0.0034	0.0194
Significance	*	*	*	*
N (kg ha -1)				
0	48.15	4.9^{ab}	4.1	0.47
23	49.6	5^{a}	4.2	0.55
46	50.6	5^{a}	4.2	0.40
69	44.3	4.7^{b}	4.0	0.29
S E (±)	2.78	0.0693	0.0988	0.0648
P value	0.4816	0.0151	0.5384	0.0827
Significance	ns	*	ns	ns
Plant density				
P1	44.8^{b}	4.8	4.03^{b}	0.45
P2	46^{b}	4.9	4.03^{b}	0.41
P3	53.6^{a}	5.0	4.4^{a}	0.42
S E (+)	2.33	0.0585	0.0836	0.0540
P value	0.0454	0.0559	0.0056	0.8678
Significance	*	ns	*	ns
CV (%)	26.66	6.43	10.73	70.20

* Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha BW = Bulb weigh in g; BL= Bulb length in cm, BD = bulb diameter in cm, ND = neck diameter in cm, SE =standard error, CV= coefficient of variation, p value =probability

Table 13 Interaction effect of hand weeding and N rate on yield components of onion

N rate (kg/ha)	**Bulb weight (g/)**		**Bulb length (cm)**		**Bulb Diameter (cm)**		**Neck Diameter (cm)**	
	Hand weeding							
	With	Without	With	Without	With	Without	With	Without
0	57	40	4.9^{b}	4.9^{bc}	4.5	3.8	0.57^{abc}	0.36^{bcde}
23	62	37	5.1^{a}	4.8^{bc}	4.7	3.7	0.49^{abcd}	0.61^{ab}
46	64	38	5.3^{a}	4.7^{bc}	4.7	3.8	0.64^{a}	0.17^{e}
69	53	35	4.7^{c}	4.6^{c}	4.4	3.7	0.30^{cde}	0.28^{de}
S E (±)	3.98		0.96		0.1365		0.0925	
P value	0.594		0.0408		0.5978		0.0336	
Significance	ns		*		ns		*	

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. SE =standard error, CV= coefficient of variation, P-value = probability.

Table 14 Interaction effect of hand weeding *and* plant density on growth parameter of onion

Plant density	Bulb weight (g/)		Bulb length (cm)		Bulb Diameter (cm)		Neck Diameter (cm)	
	Hand weeding							
	with	without	with	without	with	without	with	without
P1	58[ab]	48[b]	4.9	4.6	4.59[ab]	4.4[ab]	0.72[a]	0.19[c]
P2	61[a]	31[c]	5.0	4.7	4.6[a]	3.4[b]	0.35[bc]	0.47[b]
P3	58[ab]	32[c]	5.0	4.9	4.5[ab]	3.3[b]	0.43[b]	0.40[bc]
S E (+)	3.354		0.0803		0.11449		0.07473	
P value	0.0213*		0.0559		0.0005		0.0014	
Significance	ns		ns		***		***	

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability.

Table 15 Interaction effect of N rate and Plant density on yield component of onion

N rate (kg/ha)	Bulb Weight (g/)			Bulb Length (cm)			Bulb Diameter (cm)			Neck Diameter (cm)		
	Planting Density											
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
0	55	46	45	5.0	4.9	4.9	4	4	4.5	0.54	0.47	0.38
23	47	53	49	5.1	4.9	5.1	4.2	4.3	4.1	0.45	0.76	0.44
46	59	45.5	47	5.1	5.1	4.8	4.1	4.0	4.6	0.54	0.3	0.35
69	54	41	38	5.0	4.6	4.5	4	3.7	4.5	0.287	0.1	0.49
S E (+)	5			0.1259			0.1786			0.1202		
P value	0.4976			0.263			0.1534			0.0908		
Significance	ns			ns			ns			ns		

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability.

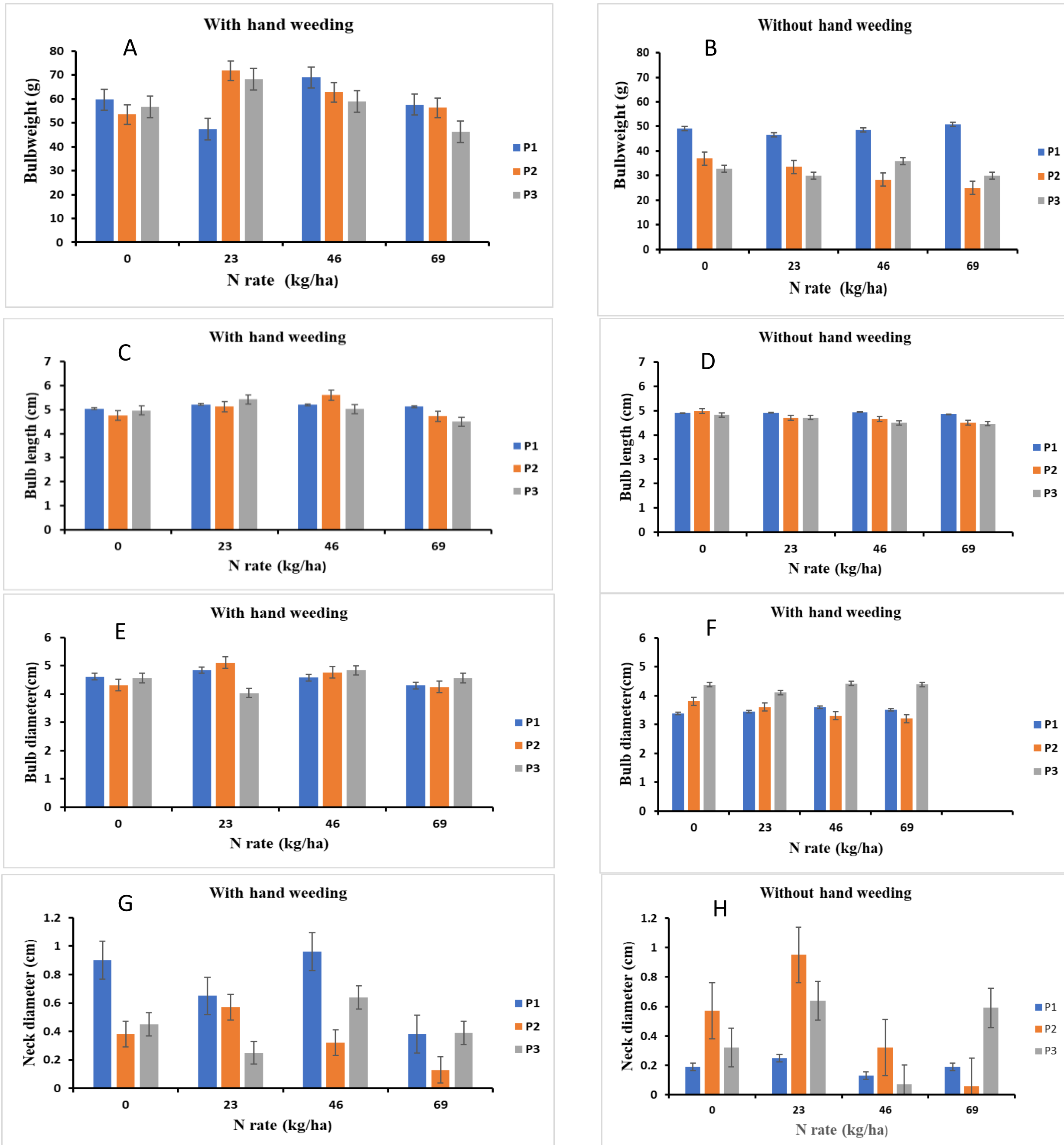

Figure 4 Interaction effects of all the factors on yield components, AB = with and without hand weeding for bulb weight, CD= with and without hand weeding for bulb length EF=with and without hand weeding for bulb diameter, GH= with and without for neck diameter= P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha

4.10.6 Marketable bulb yield

The analysis of variance revealed that marketable yield of onion was statistically significant ($p < 0.05$) effect by the hand weeding but such effects was not observed from N rate, planting density and their interaction. (Table 16). Nevertheless, marketable yield did not show significant difference by interaction of hand weeding and N rate, hand weeding and plant density as well as N rate and plant density (Table 17,18,19). Additionally, the three-factor interaction did not show significant effect on marketable yield (Fig 5). The maximum marketable yield (9965 kg ha^{-1}) was obtained from hand weeded plots. On the other hand, the minimum marketable yield (4758 kg ha^{-1}) was recorded on un weeded plots. This implies that the marketable bulb yield in weed free plots was increased by 52.3% over the un weeded onion plots. Consistent with this result, Ramachandra (2000), reported that uncontrolled weeds reduced the bulb yield by 75 per cent due to severe weed competition,

Even though the recommended rate of N for onion bulb production is 46 kg N/ha (Ethio-SHEP, 2019). most research report indicated that onion yield shows significant change when N is applied at higher rates unlike the result of this research. For instance, Jilani et al. (2004) with increase in dose of nitrogen up to 120 kg N $ha^{–1}$, the onion marketable and total bulb yield was increased, but below this level the total yield t ha– began to decrease. Similarly, Soleymani and Shahrajabian (2012), showed that the highest and the lowest marketable yield were obtained through the application of 300 kg N ha^{-1} and 0 kg N ha^{-1} respectively

The non-significant effect of the planting density may be attributed to the onion bulb diameter. Most of the highest bulb diameter recorded in weed free plots is below 5 cm. This is the least intra-row spacing to achieve the highest planting density tested in this study. The highest intra-onion plant space necessary to achieve the heaviest bulb is 5 cm, it may not be important to reduce the planting density to achieve the highest onion marketable yield. That is why the variation in the planting density did not result in significant change in the marketable yield of onion.

4.10.7 Unmarketable bulb yield

The analysis of variance revealed that unmarketable bulb yield was not statistically significant effect neither by the hand weeding nor by N rate and plant density (Table 16). In addition, interaction of hand weeding and N rate, hand weeding and plant density as well as interaction of N rate and plant density did not show significant effect on unmarketable yield (Tables 17,18 and 19). Likewise, the three factors interaction did not show significant effect on unmarketable bulb yield (Fig 5).

4.10.8 Total bulb yield

The total bulb yield that comprises both marketable and non-marketable bulb yield had significant ($p< 0.005$) effect by hand weeding but such effects was not observed from N rate, and planting density (Table 16). On the other hand, total bulb yield did not show significant variation by interaction of hand weeding and N rate and hand weeding and plant density as well as N rate and plant density (Tables 17,18 and 19). Moreover, the three-factor interaction did not show significant effect on this parameter (Fig 5). The maximum total bulbs yield (9992kg ha^{-1}) was attained by hand weeding while the lower total bulb yield (4787kg/ $ha\text{-}^{1}$) was observed in un-un weeded plot. This means that hand weeding increased the total bulb yield of onion by around 52%. The non-significant effect of other factors may be attributed to their non-significant effect on marketable and unmarketable bulb yield of onion.

4.10.9 Bulb dry weight

The analysis of variance revealed that bulb dry weight showed statistically significant ($p < 0.05$) difference by hand weeding and all factor interaction (Table 16 and Fig 5). However, such effect was not observed from N rate and planting density (Table 16). In addition, interaction of hand weeding and N rate, hand weeding and plant density as well as N rate and plant density did not show significant effect on bulb dry weight (Tables 17,18 and 19). Higher bulb dry matter (37g) was recorded from hand weeded plots. On contrary, lowest bulb dry matter yield (23 g) was obtained from un weeded plots (Table 16). This result indicated that there was 37.8% of bulb dry matter reduction due to weed competition.

The three-factor interaction effect show significant variation in bulb dry weight. Higher bulb dry weight (43.2 g) was recorded in response to received 46 kg N $ha\text{-}^{1}$with 222,222plants/ha^{-1} and by hand weeded plots. On the other hand, lowest bulb dry weight (18g) was obtained in response to received 69 kg N $ha\text{-}^{1}$with 333,333 from weedy plots. this result due to high stiff competition among crop weed plants for growth factors. Supporting the current study, excessive vegetative growth due to high rate of N may lead to less root activity, unhealthy canopy structure and a lower harvest index and cause to reduce dry matter Yang *et al*. (2000).

Table 16 Hand weeding, N rate and plant density *effect* on yield of onion

Factors	**MBY (kg/ha-^{1})**	**UMBY (kg/ha $^{-1}$)**	**TMBY (kg/ ha $^{-1}$)**	**BDW(g)**
Hand weeding				
with	9965^{a}	29.716	9992^{a}	37.4^{a}
without	4758^{b}	26.834	4787^{b}	23^{b}
S E (+)	239.82	3.1497	241.67	0.7194
P value	0.0012	0.6177	0.0012	0.0003
Significance	*	ns	*	*
N (kg ha -1)				
0	6861.10	27.3678	6888.48	30.4
23	7268.52	31.3444	7299.86	30.7
46	8111.11	28.3039	8139.42	31.8
69	7205.24	26.0828	7231.33	28
S E (+)	414.2	4.912	414.4	1.313
P value	0.1740	0.9056	0.1719	0.2263
Significance	ns	ns	ns	ns
Plant density(no/m^{2})				
P1	7497.69	27.5558	7525.24	29.3
P2	6704.86	29.4158	6734.28	30.4
P3	7881.94	27.8525	7909.80	30.9
S E (+)	361.8	4.167	362.4	1.147
P value	0.0625	0.9520	0.0622	0.6871
Significance	ns	ns	ns	ns
CV (%)	23.24	77.98	20.09	17.89

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability, MBY=marketable yield, UMBY= unmarketable yield, TMBY=total bulb yield, BDW=bulb dry weight.

Table 17 Interaction effect of hand weeding and N rate on yields of onion

N rate (kg/ha)	MBY (kg/ha-1)		UMBY (kg/ha -1)		TMBY (kg/ ha -1)		BDW(g)	
	Hand weeding							
	with	without	with	without	with	without	with	without
0	9238	4485	26	29	9264	4513	36	24.8
23	10028	4509	30	32	10058	4542	38.3	23.2
46	10901	5321	26	31	10927	5352	40.9	22.6
69	9694	4716	25	27	9720	4743	34.4	21.7
S E (+)	549		7.103		548.7		1.719	
P value	0.8584		0.9959		0.8382		0.2326	
Significance	ns		ns		ns		ns	

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability, MBY=marketable yield, UMBY= unmarketable yield, TMBY=total bulb yield, BDW=bulb dry weight.

Table 18 Interaction effect of hand weeding and plant density on yields of onion

Plant density	MBY (kg/ha-1)		UMBY (kg/ha -1)		TMBY (kg/ ha -1)		BDW(g)	
	Hand weeding							
	with	without	with	without	with	without	with	without
P1	9833.3	5162	23	32	9857	5194	37.7	21.2
P2	9180.6	4229.2	26	33	9206	4262	37.9	22.9
P3	10881.9	4882	31	24	10913	4906	36.6	25.0
SE (+)	469.1		6.078		469.2		1.464	
P value	0.374		0.4234		0.3637		0.2599	
Significance	ns		ns		ns		ns	

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability. MBY=marketable yield, UBY= unmarketable yield, TBY=total bulb yield, BDW= bulb dry weight.

Table 19 Interaction effect of N rate and Plant density on yields of onion

N rate (kg/ha)	MBY (kg/ha-1)			UMBY (kg/ha -1)			TMBY (kg/ ha -1)			BDW (g)		
	Planting Density											
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
0	6079	7111	7394	26	33	23	6105	7144	7417	32.2	29.8	29
23	7282	6843	7681	29	28	37	7312	6871	7717	29.7	32.2	30.2
46	8681	6931	8722	34	26	25	8714	6957	8747	30.1	32.5	32.6
69	7949	5935	7732	21	30	27	7970	5966	7758	26	27	25.9
SE (±)	604.76			8.8417			703.78			2.2304		
P value	0.4299			0.8984			0.4257			0.5354		
Significance	ns			ns			ns			ns		

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability. MBY=marketable yield, UMBY= unmarketable yield, TMBY=total bulb yield, BDW=bulb dry weight.

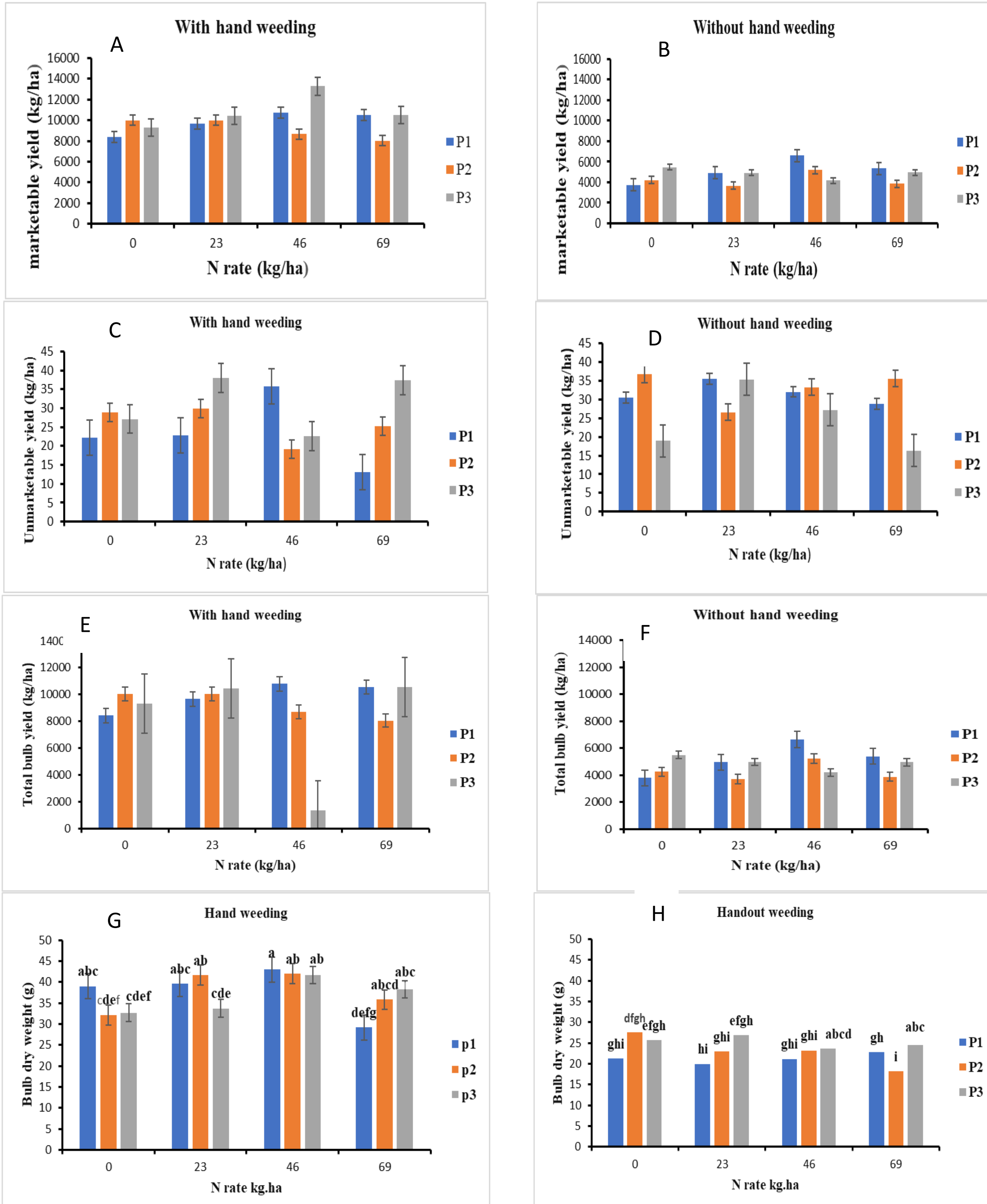

Figure 5 Interaction effects of all factors on yields of onion. AB= with and without hand weeding for marketable yield yield, CD= with and without hand weeding for unmarketable yield, EF=with and without hand weeding for total marketable yield, GH= with and without for bulb dry weight = P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha

4.11 Quality parameters of onion

4.11.2 Total Soluble Solid (TSS)

All the factors and their interaction tested did not show statistically significant effect on TSS (Tables 20, 21, 22 and 23). According to Desalegn and Aklilu (2003), TSS value of onion 7-10 % was rated as low, values 11-15 % was rated as medium, and the 15-20% were rated as high. When observing at the values from the factor effects, the TSS of the onion studied ranges from 12-13.7% and hence laid within the medium range.

4.11.3 Bulb shape index

Hand weeding, planting density and their interaction had statistically significant ($P < 0.05$) effect on bulb shape index (Table 20 and 22). Nevertheless, bulb shape index did not show significant difference by interaction of hand weeding and N rate, N rate and plant density (Tables 21 and 23). Moreover, the three-factor interaction did not show significant effect on bulb shape index (Fig 6). The highest bulb shape index (1.3) was obtained from un-weeded plots whereas the lowest bulb shape index (1.1) was recorded from weedy plots. According to King *et al.,* (1990), report bulbs from weedy plots had high bulb shape index (1.3) which considered as unacceptable bulb shape and rejected for marketing. This result indicated that weeds deteriorate the bulb shape and make it unmarketable.

The highest planting density (i.e., 666,666 plants ha^{-1}) resulted in bulbs with the shape index of 1.1 and the bulbs from the plots with the least planting density (222,222 plants ha^{-1}) had a bulb shape index of 1.2 which is considered as acceptable shape at the market (King et al.,1990).Consistent with the current study, Grant and Carter (1991), reported that increasing the plant density from 50 to 100 plants/m2 increased the bulb shape index and increased the percentage of rejected bulb shapes.

With regard to the interaction effect of hand weeding and plant density, The highest bulb shape index (1.3 and 1.4) was obtained from weedy plots with 222,222 and 333,333plants/ha whereas the lowest bulb shape index (1.1 and 1.1) was recorded from hand weeded plots with 222,222 and 333,333plants/ha. But,1.2 was recorded from hand weeding with the highest plant density (666,666plants/ha). weeds effect in bulb shape index. This result indicated that from weedy plots had high bulb shape which considered as unacceptable bulb shape and unacceptable for marketing.

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Table 20 Hand weeding, N rate and plant density effect on TSS and bulb shape index

Factors	TSS (%)	BSI
Hand weeding		
with	12.6	1.1[b]
without	12.5	1.3[a]
S E (±)	0.1927	0.0137
P value	0.6800	0.0048
Significance	ns	*
N (kg ha -1)		
0	12	1.2
23	12.8	1.2
46	12.8	1.2
69	12.2	1.2
S E (±)	0.2619	0.0282
P value	0.3548	0.7965
Significance	ns	ns
Plant density(no/m^2)		
P1	12.4	1.2[a]
P2	13	1.2[a]
P3	12.2	1.1[b]
S E (+)	0.2182	0.0241
P value	0.0765	0.0312
Significance	ns	*
CV (%)	9.80	10.66

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability. TSS= total soluble solid, BSI=bulb shape index.

Table 21 Interaction effects of hand weeding and N rate on TSS and bulb shape index

N rate (kg/ha)	TSS (%)		Bulb shape index	
	Hand weeding			
	with	without	with	without
0	12.8	11.8	1.1	1.3
23	13.0	13	1.1	1.3
46	13	13	1.1	1.27
69	12	12.5	1.1	1.27
S E (±)	0.4039		0.0385	
P value	0.2126		0.9219	
Significance	ns		ns	

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability. TSS= total soluble solid, BSI=bulb shape index.

Table 22 Interaction effects of hand weeding and plant density on TSS and bulb shape index

Plant density	TSS (%)		Bulb shape index	
	Hand weeding			
	with	without	with	without
P1	12.6	12.2	1.1[b]	1.3[a]
P2	12.8	13.3	1.1[b]	1.4[a]
P3	12.5	12	1.2[b]	1.1[b]
S E (+)	0.3481		0.0324	
P value	0.2937		0.0003*	
Significance	ns		***	

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability. TSS= total soluble solid, BSI=bulb shape index

Table 23 Interaction effects of N rate and plant density on TSS and bulb shape index

N rate (kg/ha)	TSS (%)			Bulb shape index		
	Plant density					
	P1	**P2**	**P3**	**P1**	**P2**	**P3**
0	12	12.6	12	1.3	1.2	1.1
23	13	13.7	12	1.3	1.2	1.3
46	13	13.1	12.4	1.2	1.3	1.1
69	11.7	12.7	12.4	1.2	1.3	1.1
S E (+)	0.48642			0.05022		
P value	0.6677			0.098		
Significance	ns			ns		

ns = non-significant, * Significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$, Means followed by the same letter within a column are not significantly different at 5% of significance. P = represents to plant density (no/m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha SE =standard error, CV= coefficient of variation, P-value = probability. TSS= total soluble solid, BSI=bulb shape index

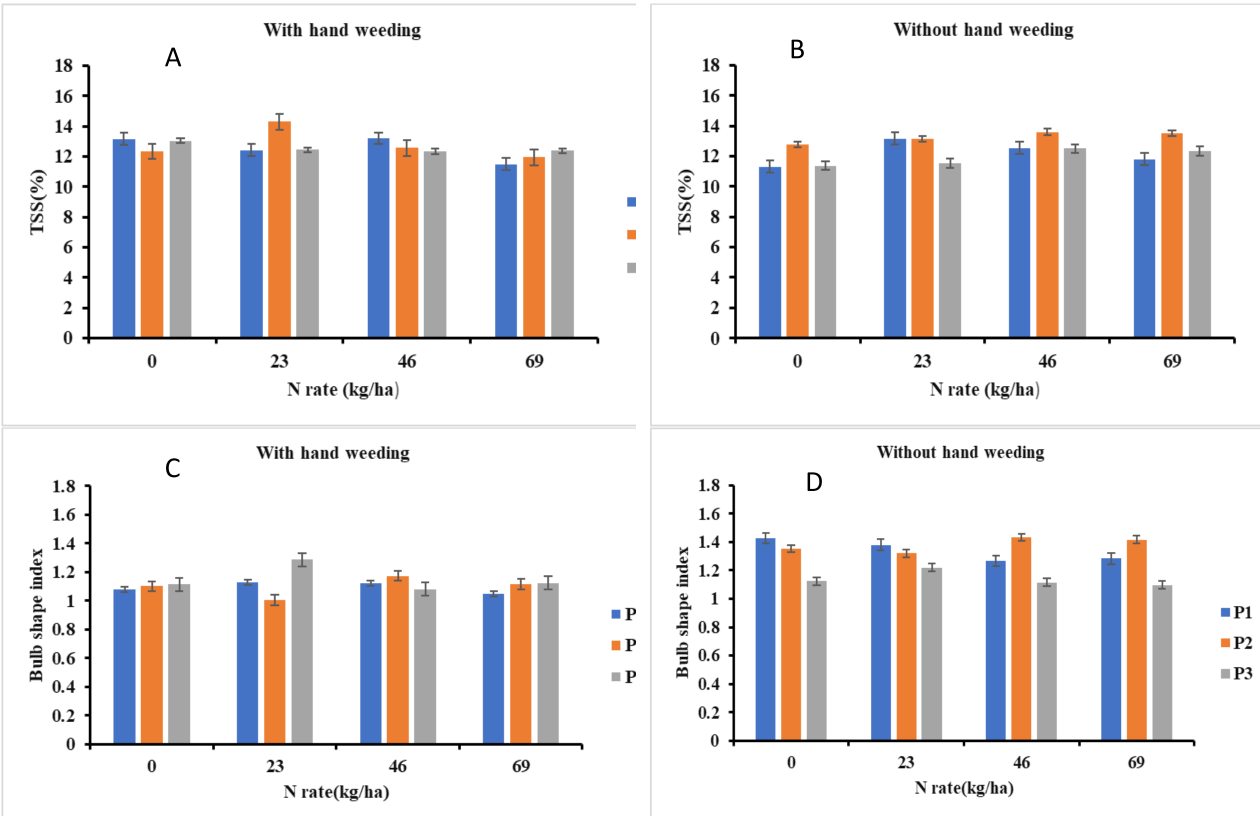

Figure 6 Interaction effects of all factors on quality parameters of onion. AB= with and without hand weeding for TSS, CD= with and without hand weeding for bulb shape index, range TSS for onion according to (Dessalegne and Aklilu 2003) low=7-10 %, medium=11-15 %, high=15-20 %, P = represents to plant density (no/ m2) P1=222,222 plants/ha p2=333,333 plants/ha, p3=666,666 plants /ha.

4.12 Correlation Analysis

Correlation analysis was done for the different response variables which help to show how the weed density and weed dry weight affected the growth and yield component of onion. It was observed that weed density was highly significantly and negatively correlated with leaf number (r= -0.3271**),leaf length (r= -0.2624**), leaf diameter (r= -0.3405**),plant height (r= -0.2639**), root length (r= -0.3002**), bulb weight (r= -0.3030**), bulb length (r= -0.2241**), bulb diameter (r= -0.3320**), neck dimeter(r= -0.1426**), bulb dry weight (r= -0.2927**), marketable yield (r= -0.2793**) and TSS (r= -0.1628**). This means that with increasing weed density, there was reduction in the growth, yield and quality (TSS) of onion. On the other hand, there was positive and significant correlation of weed density with bulb shape index (r= 0.2921**) indicating that onion bulb shape deteriorates at higher weed density.

Weed dry weight had highly significantly and negatively correlated with only marketable yield (r= -0.2715**). This indicates that weeds accumulated dry matter in cost of the marketable yield of onion.

Table 24 Correlation analysis – values of Correlation coefficient and probabilities

Parameters	Days to 90% Maturity	Leaf Number	Leaf Length (cm)	Leaf Diameter (cm)	Plant Height (cm)	Root Length (cm)	Bulb Weight (g)	Bulb Length (cm)	Bulb Diameter (cm)	Neck Diameter (cm)	Bulb Dry Weight (g)	Mark Yld (kg/ha)	Unmark Yld (kg/ha)	TB Yld (kg/ha)	TSS (%)	Bulb Shape Index	Weed Density (No./m2)	Weed DW (g/m2)
Days to 90% Maturity	1	**	ns	ns	ns	ns	ns	ns	ns	ns	**	***	ns	ns	ns	**	ns	ns
Leaf Number	0.3	1	***	***	***	***	***	***	***	***	***	***	ns	ns	ns	***	***	ns
Leaf Length (cm)	-0.0138	0.4483	1	***	***	***	***	***	***	**	***	***	ns	ns	ns	***	**	ns
Leaf Diameter (cm)	-0.0676	0.4057	0.6954	1	***	***	***	***	***	***	***	**	ns	ns	ns	***	***	ns
Plant Height (cm)	0.1037	0.7091	0.5204	0.484	1	***	***	***	***	***	***	***	**	**	ns	***	**	ns
Root Length (cm)	0.2	0.3324	0.3944	0.4141	0.4195	1	***	**	***	**	***	***	ns	ns	ns	***	**	ns
Bulb Weight (g)	0.1911	0.7569	0.6288	0.6171	0.7272	0.494	1	***	***	***	***	***	**	**	ns	***	***	ns
Bulb Length (cm)	-0.0217	0.4373	0.5607	0.4559	0.5001	0.2866	0.6599	1	***	***	***	***	ns	ns	ns	ns	ns	ns
Bulb Diameter (cm)	0.2319	0.7311	0.5841	0.5462	0.6863	0.4907	0.9489	0.6053	1	***	***	***	**	**	ns	***	***	ns
Neck Diameter (cm)	-0.0894	0.2997	0.2824	0.399	0.3614	0.2978	0.3834	0.3099	0.3906	1	***	ns	ns	ns	ns	**	ns	ns
Bulb Dry Weight (g)	0.2617	0.6893	0.5062	0.4214	0.581	0.473	0.7053	0.5842	0.7308	0.3472	1	***	ns	ns	ns	***	**	ns
Mark Yld (kg/ha)	0.3546	0.6014	0.3952	0.2432	0.4503	0.4722	0.5546	0.3508	0.5662	0.1049	0.7137	1	ns	ns	ns	***	**	**
Unmark Yld (kg/ha)	-0.064	-0.213	0.1104	-0.0107	-0.2428	-0.1413	-0.2984	-0.0434	-0.2795	-0.1129	0.0514	-0.1127	1	***	ns	***	ns	ns
TB Yld (kg/ha)	-0.0582	-0.204	0.117	-0.0067	-0.2359	-0.1338	-0.2898	-0.0377	-0.2707	-0.1114	0.0632	-0.0964	0.9999	1	ns	**	ns	ns
TSS (%)	-0.1692	0.0547	0.009	0.0499	0.0592	0.0699	-0.0312	-0.0631	-0.0536	0.1048	0.0745	-0.0327	0.0429	0.0425	1	ns	ns	ns
Bulb Shape Index	-0.2821	-0.598	-0.389	-0.3851	-0.5096	-0.4124	-0.7486	-0.1488	-0.8593	-0.2838	-0.5557	-0.4806	0.3076	0.3002	0.04	1	**	ns
Weed Density (No./m2)	-0.1697	-0.327	-0.262	-0.3405	-0.2639	-0.3002	-0.303	-0.2241	-0.332	-0.1426	-0.2927	-0.2793	0.1209	0.1166	-0.16	0.292	1	***
Weed Dry weight (g/m2)	-0.1143	-0.084	-0.045	-0.0322	-0.0351	-0.1438	-0.0782	0.0878	-0.0634	0.015	-0.0756	-0.2715	0.0581	0.0537	-0.14	0.12	0.4039	1

4.13 Partial Budget Analysis

The partial budget analysis revealed that the highest MRR (3711.5%) was recorded from plots sown at a density of 222,222 plants/ha, received N fertilizer at a rate of 46 kg N/ha and kept un-weeded for the whole growing season (Table 25). This indicates that from a unit cost incurred for the production of onion, a farmer can get a return of 3711.5 ETB which is considered as the most profitable. The second highest MRR (2689.4 ETB) was recorded from hand weeded plots transplanted at a density of 222,222 plants/ha and received 46 kg N/ha. The overall analysis indicated that the lowest onion plant density and application of N fertilizer at a rate of 46 kg N/ha is more economical than other treatments under both weed infestation scenarios. In addition, the highest MRR from un-weeded plots indicated that farmers may not have economic losses when they left their field weedy during tight production seasons.

Table 25 Dominance analysis and Marginal Rate of Return

N Rate (kg N/ha)	Plant density (No./ha)	Hand weeding	ADMY (kg/ha)	Total gross benefit (ETB/ha)	TVC (ETB/ha)	Net benefit (ETB/ha)	Dominance analysis	MRR (%)
0	222,222	with out	3383.1	152239.5	67708	84531.5		0
23	222,222	with out	4425.3	199138.5	69508	129630.5	ND	2505.5
46	222,222	with out	5949.9	267745.5	71308	196437.5	ND	3711.5
69	222,222	with out	4824.9	217120.5	73108	144012.5	D	0
0	333,333	with out	3791.7	170626.5	104167	66459.5	D	0
23	333,333	with out	3308.4	148878	105967	42911	D	0
46	333,333	with out	4666.5	209992.5	107767	102225.5	D	0
69	333,333	with out	3458.7	155641.5	109567	46074.5	D	0
0	222,222	with	7558.2	340119	128471	211648	ND	26.609
23	222,222	with	8683.2	390744	130471	260273	ND	2431.3
46	222,222	with	9675	435375	132071	303304	ND	2689.4
69	222,222	with	9483.3	426748.5	133871	292877.5	D	0
0	333,333	with	9008.1	405364.5	164930	240434.5	D	0
23	333,333	with	9008.1	405364.5	166730	238634.5	D	0
46	333,333	with	7808.4	351378	168530	182848	D	0
69	333,333	with	7225.2	325134	170330	154804	D	0
0	666,666	with out	4932.9	221980.5	208333	13647.5	D	0
23	666,666	with out	4441.5	199867.5	210133	-10265.5	D	0
46	666,666	with out	3750.3	168763.5	211933	-43169.5	D	0
69	666,666	with out	4449.6	200232	213733	-13501	D	0
0	666,666	with	8375.4	376893	269096	107797	D	0
23	666,666	with	9383.4	422253	270896	151357	D	0
46	666,666	with	11950.2	537759	272696	265063	D	0
69	666,666	with	9467.1	426019.5	274496	151523.5	D	0

TVC = Total variable cost; MRR = Marginal Rate of Return

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The most dominant weed species affecting onion growth, development and productivity *are Lanuaea capitata (spreng)Dandy, Anagallis arvensis L, Argemone Mexicana, Galinsogo parviflora Cav, Setaria pumila (poir.) Roem. & schuh, and Colchicum alpinum DC.*

Hand weeding resulted in weed dynamics and shifted weed-crop competition advantage in favor of the crop. It influenced the crop throughout its growth and development. It minimized the losses which would have been observed in the quality, yield and yield components of onion.

Variation in amount of N fertilizer resulted in weed dynamics and influenced only the bulb length. Application of higher amount of N fertilizer delayed onion maturity. Generally, varying in the amount of N fertilizer in the presence of weeds competing onion did not have effects on the crop's quality, yield and yield components.

Onion plant density did not show effect on weed dynamics and affected only some of the yield components of onion. Generally, it did not have significant effect on weeds and the crop's growth, development and productivity.

Except in bulb dry weight of onion, there were no combined effects of the factors on weed dynamics and onion productivity.

5.2 Recommendation

Dominant species found in onion field were *Lanuaea capitata* (spreng)Dandy, *Anagallis arvensis* L, *Argemone Mexicana*, *Galinsogo parviflora* Cav, *Setaria pumila* (poir.) Roem. & schuh, and *Colchicum alpinum* DC. Weed management strategies to enhance onion production and productivity must focus on these weed species.

The experiment was done for only one season and single location, it has to be repeated over seasons and locations to make a conclusive recommendation.

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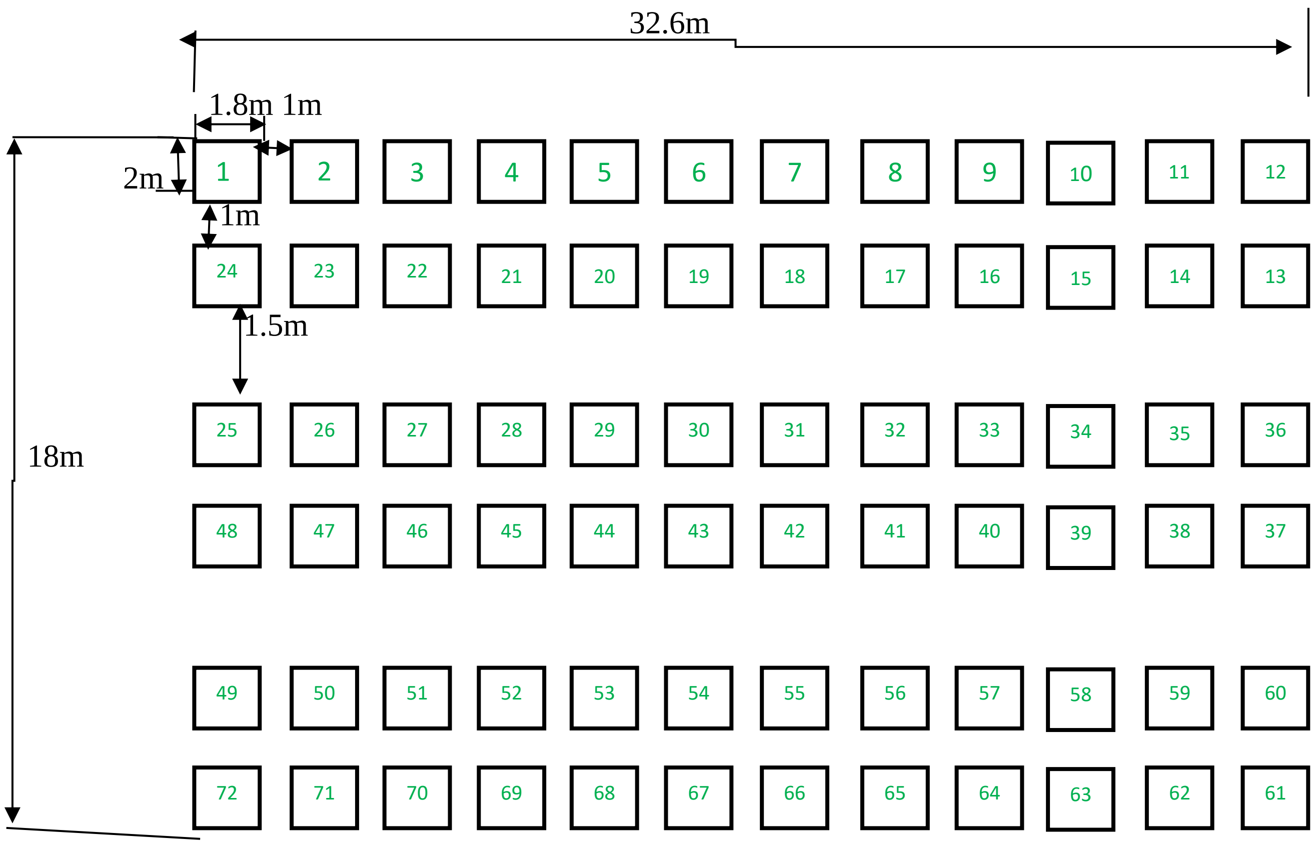
7 APPENDIX

Appendix 1 Experimental design and field layout for split plot design



Appendix 2 Treatment randomization

No.	Treatments (Subplots)	Code	Replication I		Replication II		Replication III	
			With[1]	Without[2]	Without	With	With	Without
1	P1 x 0kgN/ha	A	A (1)	I (24)	L (25)	G (48)	H (49)	K (72)
2	P1 x 23kgN/ha	B	B (2)	J (23)	K (26)	I (47)	G (50)	A (71)
3	P1 x 46kgN/ha	C	C (3)	K (22)	J (27)	E (46)	L (51)	F (70)
4	P1 x 69kgN/ha	D	D (4)	L (21)	I (28)	K (45)	I (52)	E (69)
5	P2 x 0kgN/ha	E	E (5)	F (20)	H (29)	A (44)	C (53)	B (68)
6	P2 x 23kgN/ha	F	F (6)	A (19)	G (30)	F (43)	K (54)	D (67)
7	P2 x 46kgN/ha	G	G (7)	E (18)	F (31)	B (42)	A (55)	L (66)
8	P2 x 69kgN/ha	H	H (8)	B (17)	E (32)	L (41)	F (56)	I (65)
9	P3 x 0kgN/ha	I	I (9)	C (16)	D (33)	H (40)	E (57)	C (64)
10	P3 x 23kgN/ha	J	J (10)	D (15)	C (34)	D (39)	B (58)	J (63)
11	P3 x 46kgN/ha	K	K (11)	G (14)	B (35)	J (38)	D (59)	H (62)
12	P3 x 69kgN/ha	L	L (12)	H (13)	A (36)	C (37)	J (60)	G (61)

N.B. *the letters represent the treatments in the subplot and the number in the brackets represent the plot number to which the treatment is assigned.*

[1] With hand weeding
[2] Without hand weeding

Appendix 3 Analysis variance of total weed density

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	129662.694	64831.347	1.0087	0.4978
Factor A	1	140892.014	140892.014	2.1922	0.014 s
Error	2	128540.028	64270.014		
Factor B	3	18910.708	6303.569	1.3102	0.2831 ns
AB	3	54715.153	18238.384	0.0167	0.0167 s
Factor C	2	12289.361	6144.681	1.2771	0.2890 ns
AC	2	20436.028	10218.014	2.1238	0.1317 ns
BC	6	28094.750	4682.458	0.9732	0.4546 ns
ABC	6	65988.972	10998.162	2.2859	0.0524 ns
Error	44	211696.611	4811.287		
Total	72	811226.319			

A=Hand weeding; B=Nitrogen; C =plant density, DF= degree of freedom. significant (p<0.05), ns – non significant

Appendix 4 Analysis variance of weed dry weight

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	41146.946	20573.473	0.2926	
Factor A	1	116933.684	116933.684	1.6633	0.036 s
Error	2	140601.561	70300.781		
Factor B	3	11772.161	3924.054	0.1705	0.9157 ns
AB	3	176711.708	58903.903	2.5599	0.027 s
Factor C	2	16169.235	8084.618	0.3514	0.7057 ns
AC	2	67231.615	33615.807	1.4609	0.2431 ns
BC	6	154465.361	25744.227	1.1188	0.3671 ns
ABC	6	160698.922	26783.154	1.1640	0.3428 s
Error	44	1012444.392	23010.100		
Total	72	1898175.585			

A=Hand weeding; B=Nitrogen; C =plant density, DF= degree of freedom. significant (p<0.05) NS=non significant

Appendix 5 Analysis variance of weed cover

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	8988.583	4494.292	1.1134	0.4732
Factor A	1	24716.056	24716.056	6.1231	0.021 s
Error	2	8073.028	4036.514		
Factor B	3	85.056	28.352	0.3760	0.7707 ns
AB	3	41.944	13.981	0.1854	0.9058 ns
Factor C	2	421.750	210.875	2.7966	0.0719 ns
AC	2	44.528	22.264	0.2953	0.7458 ns
BC	6	498.028	83.005	1.1008	0.3772 ns
ABC	6	398.806	66.468	0.8815	
Error	44	3317.722	75.403		
Total	72	46585.500			

A=Hand weeding; B=Nitrogen; C =plant density, DF= degree of freedom. significant (p<0.05), ns – non significant

Appendix 6 Analysis variance for days to maturity

Source	DF	Sum of Squares	Mean Square	F Value	P value
Replication	2	76.563	38.29	4.369	0.1862
Factor A	1	217.014	217.014	24.7623	0.0381 s
Error	2	17.528	8.764		
Factor B	3	317.042	105.68	10.667	0.001 s
AB	3	18.153	6.051	0.6108	
Factor C	2	20.583	10.29	1.0389	0.3624 ns
AC	2	13.361	6.681	0.6744	
BC	6	24.417	4.069	0.4108	
ABC	6	42.306	7.051	0.7117	
Error	44	435.89	9.907		
Total	72	1182.875			

A=Hand weeding; B=Nitrogen; C =plant density, DF=degree of freedom. significant (p<0.05), ns=non-significant.

Appendix 7 Interaction effect of hand weeding, N rate and plant density on days to 90% maturity

N rate kg/ha[1]	**with**			**without**		
	P1	**P2**	**P3**	**P1**	**P2**	**P3**
0	114.7	115.0	114.7	111.7	112.3	112.0
23	114.7	116.3	115.3	114.0	113.3	112.3
46	117.7	119.0	115.0	115.0	109.7	113.0
69	121.7	121.7	119.7	117.3	118.0	115.0
S E (±)	3.2					
P value	0.1682					
CV (%)	17.13					

Appendix 8 Analysis variance for leaf number

Source	DF	Sum of Squares	Mean Square	F Value	P value
Replication	2	3.134	1.567	0.9216	
Factor A	1	113.001	113.001	66.4492	0.0147 s
Error	2	3.401	1.701		
Factor B	3	6.793	2.264	1.8851	0.1460 ns
AB	3	3.206	1.069	0.8897	
Factor C	2	2.321	1.161	0.9662	
AC	2	1.008	0.504	0.4195	
BC	6	7.557	1.260	1.0488	0.4074 ns
ABC	6	6.739	1.123	0.9351	0.56 ns
Error	44	52.851	1.201		
Total	72	200.013			

A=Hand weeding; B=Nitrogen; C =plant density, DF=degree of freedom. significant (p<0.05) ns, non-significant

Appendix 9 Analysis variance for leaf length

Source	DF	Sum of Squares	Mean Square	F Value	P value
Replication	2	41.512	20.756	1.5080	0.3987
Factor A	1	261.823	261.823	19.0219	0.0488 s
Error	2	27.529	13.764		
Factor B	3	64.718	21.573	1.2162	0.3150 ns
AB	3	51.027	17.009	0.9590	
Factor C	2	118.030	59.015	3.3272	0.0451 s
AC	2	13.590	6.795	0.3831	
BC	6	162.650	27.108	1.5283	0.1914 ns
ABC	6	26.301	4.383	0.2471	
Error	44	780.433	17.737		
Total	72	1547.613			

A=Hand weeding; B=Nitrogen; C =plant density., DF= degree of freedom, significant (p<0.05), ns – non significant,

Appendix 10 Analysis variance for leaf diameter

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	0.281	0.140	8.3554	0.1069
Factor A	1	0.390	0.390	23.2149	0.0405 s
Error	2	0.034	0.017		
Factor B	3	0.207	0.069	1.3367	0.2747 ns
AB	3	0.077	0.026	0.4976	
Factor C	2	0.242	0.121	2.3479	0.1074 ns
AC	2	0.175	0.088	1.6971	0.1950 ns
BC	6	0.264	0.044	0.8526	
ABC	6	0.136	0.4384		
Error	44	2.272	0.052		
Total	72	4.079			

A=Hand weeding; B=Nitrogen; C =plant density, DF=degree of freedom. significant (p<0.05), ns – non significant

Appendix 11 Analysis variance for plant height

Source	DF	Sum of Squares	Mean Square	F Value	P value
Replication	2	19.757	9.879	0.6395	
Factor A	1	765.057	765.057	49.5258	0.0196 s
Error	2	30.895	15.448		
Factor B	3	64.225	21.408	1.2770	0.2940 ns
AB	3	17.279	5.760	0.3436	
Factor C	2	49.386	24.693	1.4729	0.2403 ns
AC	2	8.017	4.008	0.2391	
BC	6	132.033	22.006	1.3126	0.2717 ns
ABC	6	127.969	21.328	1.2722	0.2897 ns
Error	44	737.640	16.765		
Total	72	1952.259			

A=Hand weeding; B=Nitrogen; C =plant density, DF=degree of freed om significant (p<0.05), ns, non -significant,

Appendix 12 Analysis variance for root length

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	13.920	6.960	0.8239	
Factor A	1	49.336	49.336	5.8402	0.1369 ns
Error	2	16.895	8.448		
Factor B	3	0.775	0.258	0.1093	0.9545 ns
AB	3	1.000	0.333	0.1410	0.9349 ns
Factor C	2	1.777	0.888	0.3759	0.6889 ns
AC	2	1.285	0.643	0.2719	0.7632 ns
BC	6	21.394	3.566	1.5086	0.1977 ns
ABC	6	12.039	2.007	0.8489	
Error	44	103.998	2.364		
Total	72	222.419			

A=Hand weeding; B=Nitrogen; C =plant density, DF=degree of freedom. significant (p<0.05), ns – non significant

Appendix 13 Analysis variance for bulb weight

Source	DF	Sum of Squares	Mean Square	F Value	P value
Replication	2	123.110	61.555	0.6931	
Factor A	1	8521.651	8521.651	95.9479	0.0103 s
Error	2	177.631	88.81		
Factor B	3	411.710	137.237	0.8323	
AB	3	316.835	105.612	0.6405	
Factor C	2	1096.120	548.060	3.3240	0.0452 s
AC	2	1385.236	692.618	4.2008	0.0214 s
BC	6	899.964	149.994	0.9097	
ABC	6	770.793	128.466	0.7792	
Error	44	7254.672	164.879		
Total	72	20957.724			

A=Hand weeding; B=Nitrogen; C =plant density, DF=degree of freedom. significant ($p<0.05$), ns – non significant,

Appendix 14 Analysis variance for bulb length

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	0.095	0.048	2.5625	0.2807
Factor A	1	1.711	1.711	91.9204	0.0107 **s**
Error	2	0.037	0.01		
Factor B	3	1.159	0.386	3.8815	0.0151 s
AB	3	0.894	0.298	2.9949	0.0408 **s**
Factor C	2	0.613	0.307	3.0816	0.0559 s
AC	2	0.045	0.022	0.2243	
BC	6	0.793	0.132	1.3283	0.2650 ns
ABC	6	0.649	0.108	1.0875	0.3848 ns
Error	44	4.378	0.099		
Total	72	10.374			

A=Hand weeding; B=Nitrogen; C =plant density., DF= degree of freedom, significant ($p<0.05$), ns – non significant,

Appendix 15 Analysis variance for bulb diameter

Source	DF	Sum of Squares	Mean Square	F Value	P value
Replication	2	0.210	0.105	2.5068	0.2852
Factor A	1	12.152	12.152	290.3561	0.0034 s
Error	2	0.084	0.042		
Factor B	3	0.438	0.146	0.7322	
AB	3	0.378	0.126	0.6328	
Factor C	2	2.332	1.166	5.8507	0.0056 s
AC	2	3.638	1.819	9.1290	0.0005 s
BC	6	1.986	0.331	1.6609	0.1534 ns
ABC	6	1.092	0.182	0.9133	
Error	44	8.768	0.199		
Total	72	31.077			

A=Hand weeding; B=Nitrogen; C =plant density. DF= degree of freedom, significant (p<0.05), ns – non significant

Appendix 16 Analysis variance for neck diameter

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	0.052	0.026	3.5075	0.2219
Factor A	1	0.370	0.370	50.0632	0.0194 s
Error	2	0.015	0.007		
Factor B	3	0.658	0.219	2.3777	0.0827 ns
AB	3	0.876	0.292	3.1672	0.0336 s
Factor C	2	2.332	0.013	0.1422	
AC	2	1.413	0.706	7.6617	0.0014 s
BC	6	1.089	0.182	1.9688	0.0908 ns
ABC	6	0.476	0.079	0.8596	
Error	44	4.057	0.092		
Total	72	9.031			

A=Hand weeding; B=Nitrogen; C =plant density. DF= degree of freedom, significant (p<0.05), ns – non significant

Appendix 17 Analysis variance for marketable yield

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	7142572.716	3571286.358	6.2673	
Factor A	1	488137503.715	488137503.71	856.6453	0.0012 s
Error	2	1139649.044	569824.522		
Factor B	3	15216847.219	5072282.406	1.7333	
AB	3	2225899.560	741966.520	0.2535	
Factor C	2	17294036.699	14796784.506	2.9548	0.0625 ns
AC	2	5887237.757	2943618.879	1.0059	0.3740 ns
BC	6	17771531.801	2961921.967	1.0121	0.4299 ns
ABC	6	28886235.304	4814372.551	1.6452	0.1575 ns
Error	44	128761438.67	2926396.334		
Total	72	712462952.495			

A=Hand weeding; B=Nitrogen; C =plant density, DF=degree of freedom, significant ($p<0.05$), ns – non significant

Appendix 18 Analysis variance for unmarketable yield

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	552.685	276.343	0.6317	
Factor A	1	149.645	149.645	0.3421	0.6177 ns
Error	2	874.953	437.476		
Factor B	3	271.959	90.653	0.1864	0.9056 ns
AB	3	30.418	10.139	0.0209	0.9959 ns
Factor C	2	47.835	23.918	0.0492	0.9520 ns
AC	2	854.332	427.166	0.8786	0.4234 ns
BC	6	1059.690	176.615	0.3633	0.8984 ns
ABC	6	1085.944	180.991	0.3723	
Error	44	21393.082	486.206		
Total	72	26320.544			

A=Hand weeding; B=Nitrogen; C =plant density, DF= degree of freedom. significant ($p<0.05$), ns – non significant

Appendix 19 Analysis variance of total bulb yield

Source	DF	Sum of Squares	Mean Square	F Value	P value
Replication	2	7262043.635	3631021.818	6.3229	0.1366
Factor A	1	487596075.9	487596075.9	849.0721	0.0012 s
Error	2	1148538.664	574269.332		
Factor B	3	15235860.787	5078620.262	1.7441	0.1719 ns
AB	3	2217087.750	739029.25	0.2538	
Factor C	2	17242746.479	8621373.240	2.9608	0.0622 ns
AC	2	6028353.083	3014176.542	1.0351	0.3637 ns
BC	6	17799630.685	2966605.114	1.0188	0.4257 ns
ABC	6	28817244.616	4802874.1	1.6494	0.1564 ns
Error	44	128121288.323	2911847.462		
Total	72	711468869.925			

A=Hand weeding; B=Nitrogen; C =plant density, DF= degree of freedom. significant (p<0.05), ns – non significant

Appendix 20 Analysis variance of bulb dry weight

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	72.481	36.241	39.3682	0.0248
Factor A	1	3675.102	3675.102	3992.2725	0.0003 s
Error	2	1.841	0.921		
Factor B	3	132.901	44.300	1.5120	0.2246 ns
AB	3	129.117	43.039	1.4689	0.2360 ns
Factor C	2	21.995	10.998	0.3753	
AC	2	81.809	40.904	1.3961	0.2583 ns
BC	6	149.974	24.996	0.8531	
ABC	6	430.116	71.686	2.4466	0.0396 s
Error	44	1289.191	1289.191	29.300	
Total	72	5984.526			

A=Hand weeding; B=Nitrogen; C =plant density, DF= degree of freedom. significant (p<0.05), ns – non significant

Appendix 21 Analysis variance of total TSS (%)

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	0.806	0.403	0.1774	
Factor A	1	0.519	0.519	0.2282	0.6800 ns
Error	2	4.544	2.272		
Factor B	3	5.040	1.680	1.1110	0.3548 ns
AB	3	6.948	2.316	1.5317	0.2196 ns
Factor C	2	8.245	4.123	2.7265	0.0765 ns
AC	2	3.811	1.905	1.2601	0.2937 ns
BC	6	6.155	1.026	0.6785	0.6677 ns
ABC	6	8.649	1.441	0.9533	
Error	44	66.530	1.512		
Total	72	111.246			

A=Hand weeding; B=Nitrogen; C =plant density, DF= degree of freedom. significant (p<0.05), ns – non significant

Appendix 22 Analysis variance of total bulb shape index

Source	DF	Sum of Squares	Mean Square	F value	P value
Replication	2	0.018	0.009	9.6390	0.0940
Factor A	1	0.524	0.524	557.6857	0.0018 s
Error	2	0.002	0.001		
Factor B	3	0.007	0.002	0.1513	
AB	3	0.019	0.006	0.3863	
Factor C	2	0.130	0.065	3.9673	0.0261 s
AC	2	0.316	0.316	0.158	0.0003 s
BC	6	0.156	0.026	1.5837	0.1746 ns
ABC	6	0.049	0.008	0.4951	
Error	44	0.721	0.016		
Total	72	1.942			

A=Hand weeding; B=Nitrogen; C =plant density, DF= degree of freedom. significant (p<0.05), ns – non significant