INTEGRATING WEED MANAGEMENT WITH NANO NITROGEN IN OKRA

(*Abelmoschus esculentus* (L.) Moench)

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(2020-11-066)

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VELLAYANI, THIRUVANANTHAPURAM-695 522
KERALA, INDIA

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by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Integrating weed management with nano nitrogen in okra (*Abelmoschus esculentus* (L.) Moench)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place : Vellayani

Date: 21-09- 2023

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CERTIFICATE

Certified that this thesis entitled **"Integrating weed management with nano nitrogen in okra (*Abelmoschus esculentus* (L.) Moench)"** is a record of research work done independently by Ms.Navaneetha C. under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation / symbol	**Expansion**
%	per cent
@	at the rate of
₹	Indian rupee
μ	Micro
°C	degree Celsius
B:C	benefit cost
BLW	broad leaved weeds
CD	critical difference
cm	centimetre
cm^2	square centimetre
DAS	days after sowing
DMP	dry matter production
$dS\ m^{-1}$	decisiemens per metre
EC	electrical conductivity
et al.	co-workers
fb	Followed by
Fig.	figure
FYM	farmyard manure
g	gram
$g\ m^{-2}$	gram per meter square
$g\ m^{-2}\ day^{-1}$	gram per meter square per day
ha	hectare
ha^{-1}	per hectare
HI	harvest index

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INTRODUCTION

1. INTRODUCTION

One of the most crucial factors determining the yield advantage of a crop is weed suppression. Although increased nutritional status may increase crop competitiveness, some weeds are more adept at using the available extra nutrients than the crops. Hence, controlling crop fertilization is a crucial part of an integrated weed control strategy that protects crop output and gradually lowers weed populations.

An important part of an integrated weed control system that safeguards agricultural productivity and gradually lowers weed populations is managing crop fertilization. Of this, nitrogen fertilizer plays a crucial role in influencing the crop weed competition. One of the most significant factors influencing yield advantage has been weed control with balanced nitrogen fertilization. Weeds are competent in taking up the nutrients speedier and in moderately greater amounts than crops. When there is a high density of weeds, fertilizer treatment may considerably promote weed growth, suppressing crop growth. In order to decrease weed interference in crops, managing the ways of crop nutrition is a potential agronomic practice.

Heavy weed incidence is one of the main obstacles in raising okra as a vegetable. Initial slow growth rate and increased space between plants are the shortfalls being utilized by weeds to hinder growth of okra. The yield loss in okra due to weed competition ranged from 37.98 to 92.35 per cent (Shamla *et al*., 2017). Crop weed competition considered critical during the growth period of okra is reported as 15 to 30 DAS by Rana *et al*. (2011).

Weed growth is generally consistently impacted by the nitrogen application strategy. Balanced nitrogen fertilization and the interaction between crop and weed flora affects output. According to studies, nitrogen fertilization can be controlled to increase crop competitiveness. With its ease of foliar application and ability to minimise weed competition over time with enhanced nutrient usage efficiency, nano urea presents a great opportunity for crop nitrogen management.

The primary objective of nanofertilizers is aimed to enhance the availability of nutrients leading to higher nutrient use efficiency (Suppan, 2013). Watts *et al*. (2012) observed a significant improvement in yield due to foliar application of nano particles in their findings. Nanoscale urea particles are present in nanourea that has been created through nanotechnology. The average physical size of nanourea particles is between 20 and 50 nm, and the weight percentage of nitrogen in IFFCO nanourea's nano form is 4%. Most crops can use nanourea as a source of nitrogen by foliar application since it has a higher utilization efficiency than regular urea. (IFFCO, 2021).

The manual method is the one that is most frequently used to control weeds in okra. Reddy *et al*. (2001) reported that the highest weed control efficiency was obtained with hand weeding twice at 25 DAS and 40 DAS in okra. However, the lack of labour and rising labour costs has forced farmers to look for alternate weed control strategies.

The most efficient and cost-effective way of weed management in okra is manual weeding integrated with chemical methods. Jalendhar (2010) described that application of oxyfluorfen as pre-emergence treatment at a rate of 0.15 kg ha^{-1} combined with one hand weeding at 30 DAS resulted in the highest level of weed control efficiency compared to other weed management practices studied. Shamla *et al*. (2017) reported that pre-emergence pendimethalin application caused a reduction in weed population and dry matter production during the initial period of the crop. However, it was observed that the weed population and dry matter increased subsequently. There is a need to determine if nitrogen application methods and weed control methods together can enhance the competitive ability of crop against weeds and boost yield and productivity of okra.

In this background, the present study is aimed to develop an integrated weed management strategy based on nitrogen management using nano nitrogen to reduce crop weed competition in okra.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The application of fertilizers and inherent fertility of soil have a significant influence on various aspects of weed dynamics including diversity, growth, persistence, and ultimately the crop-weed competition between weeds and crops. Therefore, it is essential to balance the use of chemical fertilizers to meet the nutrient requirement of the crop while simultaneously minimizing weed growth. One of the most significant factors influencing the yield advantage has been weed control with balanced nitrogen fertilization. This calls for formulating an integrated weed management strategy in okra based on nitrogen management using nano-urea and weed management using herbicides. In the following chapter an effort has been made to review the research works on these aspects as presented.

2.1 CROP FERTILIZATION AS A TOOL FOR WEED MANAGEMENT

Okra is a valuable vegetable crop with significant economic importance, commonly cultivated in tropical and subtropical regions. However, its successful cultivation faces a major challenge in the tropics, where weed infestation poses a significant obstacle to vegetable production. As noted by Rana *et al.* (2011), the presence of weeds can lead to a staggering 70 to 80 per cent reduction in vegetable yields. These invasive plants present a looming threat to crop production due to their aggressive, persistent and adaptable nature compared to other crops. They demonstrate remarkable resilience in unfavourable environments and exhibit a higher demand for nutrients and water from the soil, ultimately leading to decreased crop yields. Furthermore, the substantial nutrient consumption by many agricultural weeds can deprive crops of essential nutrients required for their healthy growth.

When compared to crop plants, some weeds may accumulate higher mineral nutrient concentrations than necessary for their growth (Alkamper, 1976). Such ‘luxury consumers take advantage of the fertilisation more rather than crop plants. According to Blackshaw *et al*. (2003), higher soil nutrient levels also promote the growth of different weed species. The availability of nutrients in the soil affects weed growth and development, their ability to germinate, establish and persist in the soil. Since weeds acquire nutrients more quickly and effectively than crop plants do, fertiliser applications may benefit weeds more than crops (Balasubramanian and Palaniappan, 2004).

The way crops are fertilized significantly influences the interaction between weeds and crops, as well as the development of weed communities. To efficiently reduce weed interference in crops and enhance nutrient uptake, a valuable cultural approach involves manipulating crop fertilization. Given that weeds typically absorb nutrients more aggressively than crops, it is advantageous to adjust the timing, placement, and source of fertilizers, ensuring that crops receive priority access to essential nutrients (Nichols *et al*., 2015).

According to Yin *et al*. (2006), providing an optimal combination of nitrogen (N), phosphorus (P), and potassium (K) fertilization can result in the development of a dense and uniform crop canopy, which, in turn, reduces the availability of light for weeds. This can have implications for weed diversity as well. The fertilization process may influence weed populations through the selection pressures it imposes (Murphy and Lemerle, 2006). Moreover, in areas with high weed density, weed biomass is likely to increase with fertilization (Guza *et al*., 2008). Furthermore, the effectiveness of herbicides can be altered by fertilization practices (Mithila *et al*., 2008). The dosage, timing, application technique, and type of fertilizer used can all play a role in shaping weed dynamics, persistence, distribution, emergence, dormancy, and growth characteristics.

2.1.1 Nitrogen based weed management

As stated by Moody (1981), nitrogen (N) is the primary nutrient that becomes limited in the presence of crop-weed competition. This competition becomes more pronounced at low N rates compared to high N rates. Different weed species respond differently to N fertilization. It is crucial to maintain an adequate level of extractable N in the soil solution for optimal plant growth. However, excessive soil enrichment with nitrogen beyond the crop's requirements can be utilized by various weed species infesting the crop, leading to increased weed infestation and their ability to compete with the crop. This ultimately results in significant production losses for the crop.

Mahajan and Timsina (2011) found that in direct-seeded rice production, increasing the N application rate to 150 kg ha^{-1} significantly improved yields when weeds were well managed. However, inadequate weed management led to drastic reductions in crop yields. Therefore, it is essential to implement effective weed control strategies in addition to balanced fertilization. While providing fertilizer is beneficial in producing higher net returns, it cannot fully compensate for the yield losses caused by weed competition. Thus, weed management remains a necessary aspect of successful crop production.

2.1.2 Soil application of nitrogen

According to the estimates, a significant amount of nutrients from applied fertilizers is lost to the environment, with approximately 40 to 70 per cent of nitrogen, 80 to 90 per cent of phosphorus, and 50 to 90 per cent of potassium not reaching the plant (Trenkel, 1997; Ombodi *et al.*, 2000). These losses have adverse effects both environmentally and economically.

To achieve high levels of productivity in intensive crop production, additional plant nutrition is often required, and this can be supplied through foliar or soil application. While delivering nutrients to the soil is a commonly used method, it has notable drawbacks concerning the availability of nutrients to the plants. According to Alshaal and El-Ramady (2017), certain inorganic nutrients exist in insoluble forms and remain fixed in the soil, making them susceptible to leaching through irrigation or rainfall. Various factors such as chemical leaching, drift, runoff, evaporation, hydrolysis by soil moisture, photolytic and microbiological destruction can further reduce the concentration of the applied nutrients that ultimately reach the targeted site in the soil. As a result, the actual amount of nutrients available to the plants from the soil application is significantly limited.

According to DiTomaso (1995), research has shown that banded or deep fertilizer applications are more effective in reducing weed growth when compared to broadcast applications. This finding has been consistently supported by various studies, which have demonstrated that both inorganic and organic fertilizers applied in a banded or injected manner are more advantageous for weed control than broadcast applications (Sengxua *et al*., 2019).

2.1.2.1 Soil application of nitrogen and weed growth

In the study conducted by Blackshaw *et al*. (2004), it was observed that the biomass of weeds consistently increased when 168 kg of nitrogen per hectare was applied to the soil compared to when no nitrogen was applied. The research demonstrated that the application of nitrogen fertilizer during spring resulted in higher nitrogen availability, which in turn led to increased weed growth. However, the specific impact of nitrogen on weed emergence varied depending on the weed species, seed source, and prevailing environmental conditions. The timing of N fertilizer application can also influence weed germination, emergence, and their overall competitiveness with the crop. These findings highlighted the importance of considering the appropriate timing and dosage of nitrogen fertilization to effectively manage weed growth and reduce competition in agricultural fields.

When examining the impact of different nitrogen (N) placement techniques on weed growth, it was found that subsurface banded or point-injected N applications in spring wheat consistently resulted in lower weed shoot N concentration and biomass compared to surface broadcast N applications. Additionally, at the conclusion of the four-year study, the weed seedbank was reduced by 25 to 63 per cent, depending on the weed species, in comparison to broadcast N (Blackshaw *et al.*, 2004). This suggested that using subsurface banded or point-injected N techniques can be beneficial in controlling weed growth and reducing the weed seedbank over time.

2.1.3 Foliar application of nitrogen

Foliar application of fertilizers offers a solution to overcome the limitations associated with soil application. According to Narang *et al*. (1997), foliar application is more efficient than soil application in terms of excellent plant utilization and lower cost per unit area. It has been found that foliar feeding is the fastest method to address nutrient deficiencies, leading to increased crop yield and improved crop quality (Roemheld and El-Fouly, 1999). Additionally, foliar application minimizes environmental pollution and enhances nutrient utilization by reducing the amount of fertilizers added to the soil (Abou-El-nour, 2002). This highlighed the effectiveness of foliar application as a valuable technique for providing nutrients to plants, ensuring better nutrient absorption, and contributing to sustainable agricultural practices.

The availability of nutrients applied to the soil depends on various soil-related factors, and nutrient uptake by plants through soil application may take time. In contrast, foliar nutrition offers a more immediate and direct route for nutrients to enter leaf cells and reach the cytoplasm, bypassing soil-related limitations. When nutrients are fixed in the soil, their availability to plants throughout the growing season decreases, especially if there is a lack of soil moisture, which can lead to plant wilting and nutrient wastage. As the growing fruits become the primary sinks for assimilates, the roots may be deprived of the energy required for efficient nutrient absorption, resulting in reduced crop growth and yield. At this stage, foliar nutrients can prove beneficial. The plant's response to foliar treatment is relatively quick, taking around three to four days, compared to soil application, which may take five to six days for the plant to respond. Regardless of the soil condition, foliar nutrition facilitates the rapid and efficient absorption of nutrients, enhancing the roots' capacity to absorb nutrients from the soil (Kannan, 2010). This emphasizes the advantages of foliar application in providing nutrients to plants promptly and effectively, especially when immediate nutrient uptake is essential for crop growth and productivity.

2.1.3.1 Foliar application of nitrogen and weed growth

The effects of fertility treatments on weed-crop competition can vary depending on the application location, timing, nutrient amount, and nutrient source.

2.1.4 Nanourea

Foliar applied fertilizers, which are salt-based (cations/anions), encounter difficulties in penetrating the interior plant tissue cells due to various structural barriers. Studies conducted by Flischer *et al.* (1999), Benzon *et al.* (2015), and Schwab *et al.* (2015) revealed that cell walls have pores with sizes ranging from 5 to 20 nm.

However, nanoparticles, with diameters smaller than the pore size of the plant cell wall, can aggregate and easily pass through the cell wall to reach the plasma membrane (Moore *et al*., 2006; Navarro *et al*., 2008). Nano-carriers deliver nutrients to the appropriate location and time, reducing the additional quantity of active chemicals deposited in the plant system and improving nutrient uptake efficiency. Nano-fertilizers are considered smart delivery systems due to their large surface area, sorption capacity, and controlled-release kinetics to specific areas (Rameshaiah *et al*., 2015; Solanki *et al*., 2015). These features make nano-fertilizers advantageous for enhancing nutrient delivery and uptake in plants.

In their study, Tarafdar *et al*. (2012) reported a notable increase in crop yield as a result of foliar application of nanofertilizers. The objective of nanofertilizers is to enhance the availability of nutrients to the leaves, thereby improving nutrient use efficiency (Suppan, 2013). This indicated that the use of nanofertilizers holds promise in maximizing crop productivity and optimizing nutrient utilization in agriculture.

Nanourea, produced using nanotechnology, contains nanoscale nanourea particles. These particles have an average size ranging from 20 to 50 nm, and the nano form of IFFCO nanourea contains 4 per cent nitrogen by weight. The nitrogen present in nanourea effectively fulfil the crop's nitrogen requirements. It serves as a suitable nitrogen source for most crops and exhibits higher efficiency compared to conventional urea. (IFFCO, 2021).

2.1.4.1 Foliar application of nanourea and crop growth

Nanofertilizers play a crucial role in enhancing the biochemical and physiological processes of crops by increasing nutrient availability. This, in turn, stimulates metabolic processes, promoting meristematic activities and leading to higher apical growth and an increase in the photosynthetic area of crops.

Marimuthu and Surendran (2015) found that foliar spraying of nano formulations containing NPK and micronutrients resulted in increased plant height and the number of branches in black gram. Abdel-Aziz *et al*. (2018) reported that nano NPK enhanced leaf growth in wheat by facilitating nutrient availability through easy penetration of the formulation through leaf stomata via gas uptake. In another study, Rostami *et al*. (2017) observed a remarkable 165 per cent increase in the dry weight of peppermint leaves when nitrogen nanofertilizer was applied through foliar spraying. These findings highlighted the significant positive impact of nanofertilizers on crop growth and development, demonstrating their potential as effective tools in modern agriculture.

2.2 WEED MANAGEMENT IN OKRA

Okra or bhindi is a widely cultivated crop globally, primarily valued for its young, immature fruits. However, a significant challenge in okra cultivation is the prevalence of weeds, which poses a major constraint. The wide spacing commonly adopted for okra cultivation and its initially slow growth contributed to this issue (Ameena *et al*., 2013).

Throughout the growing season of okra, various weed species frequently reoccur, causing considerable difficulties as they vigorously compete with the crop. This competition becomes particularly intense in the case of direct-seeded vegetables like okra. Weeds consume nutrients, moisture, and sunlight, all the while competing for the space that should ideally be dedicated to the growth of the okra plants. This competition between okra and weeds significantly affects the overall productivity and success of okra cultivation.

2.2.1 Critical period of crop weed competition

Weeds take advantage of moisture, soil fertility, and various environmental factors to hinder the growth of okra, especially during its slow initial stages. This competition from weeds weakens and stresses the crop, leading to reduced production and compromised quality. Studies suggest that weed competition in okra can result in production losses ranging from 54.1 to 90.6 per cent. According to Singh *et al*. (1981), the critical period of crop-weed competition in okra spans up to 2 to 6 weeks after planting, during which effective weed control measures are essential to minimize the negative impact on okra growth and yield.

The critical period of crop-weed competition (CPWC) refers to the phase within the crop's life cycle during which effective weed management is crucial to prevent significant yield losses. Understanding this critical period aids in making decisions regarding the timing of weed control measures and reducing herbicide usage. Depending on the intensity and type of crop, these weeds can capture around 30 to 60 per cent of the applied nutrients (Walia and Gill, 1995).

Rasheed *et al*. (2009) conducted a study on okra and found that weed infestation two weeks after planting led to a substantial reduction of 79.8 and 72.5 per cent in fresh fruit yield during the years 2006 and 2007, respectively. Furthermore, weed infestation eight weeks after planting resulted in yield losses of 19.8 and 19.6 percent during the same respective years. This highlights the critical importance of effectively managing weeds during specific periods to ensure optimal okra yields.

According to Rana *et al*. (2011), the critical period of crop-weed competition during the growth of okra is reported to be from 15 days after sowing (DAS) to 30 DAS. Weeds with similar morphologies tend to be more competitive than those with different morphologies due to their fast growth patterns. Weeds have an advantage over the crop as they establish early and grow rapidly. The root exudates of *Cyperus rotundus* contain inhibitory compounds that hinder the growth of okra, as noted by Ameena *et al*. (2014).

Crops and weeds compete for growth factors, leading to delayed maturity and reduced production. Weeds significantly deplete nutrients from the soil. Maheswari and Arthanari (2017) reported that weeds took away 90.50 kg ha^{-1} of N, 22.70 kg ha^{-1} of P, and 62.70 kg ha^{-1} of K from unweeded plots. They also found that brinjal (eggplant) increased its nutrient uptake after adopting weed management strategies.

2.2.2 Weed flora in okra

Grasses, sedges, and broad-leaved weeds (BLW) were the three main groups of weeds that have been identified in the production of okra. Each species has a different density that varies depending on the soil and climate. *Ageratum conyzoides* L., *Talinum triangulare* (Jacq.), and *Syndrella nodiflora* (L.) Gaertn. were the main BLW while *Panicum maximum* Jacq. was the main grass weed (Oroka *et al*., 2016). Shamla *et al*. (2017) stated that *Digitaria ciliaris* Retz. (Koeler) and *Panicum maximum* were the grass weeds found in the okra experimental plots, and the BLW present were *Borreria hispida* K. Schum., *Euphorbia geniculata* L., *Sida acuta*, *Cleome burmanii*, *Phyllanthus amarus*, and *Alternanthera bettzickiana* (Regel) G. Nicholson.

According to Rajasree *et al*. (2017), broad leaved weeds predominated over grasses as the main weed flora in okra. *Parthenium hysterophorus* L., *Alternanthera triandra* Lam., *Amaranthus viridis* L., *Portulaca oleracea*, *Euphorbia hirta* L., *Chenopodium album* L., *Physalis minima* L., *Sonchus arvensis* L., and *Trianthema portulacastrum* L. were the major BLW present. According to Kapoor (2020), there were grasses, BLW, and sedges in the experimental okra field, but grasses showed the most diversity. There were different types of grasses present, including *Avena fatua* L., *Cynodon dactylon*, *Digera arvensis*, *Echinochloa colona* (L.), and *Sorghum halepense* (L.) Pers. *Amaranthus spinosus* L., *Chenopodium album*, and *Convolvulus arvensis* L. were the broad leaf weeds found.

The main weeds in okra, according to Bhalla and Parmar (1982), were *Setaria glauca*, *Commelina benghalensis*, *Physalis minima*, *Ageratum conyzoides*, *Amaranthus viridis*, and *Cyperus rotundus*. *Boerhavia repanda* Willd., *Digera arvensis* Forsk., and *Phyllanthus niruri* L. were the BLW that were seen in the field.

According to Sainudheen (2000), *Cynodon dactylon* and *Cyperus rotundus* are the two most common annual weeds in okra, along with *Cyperus iria*, *Digitaria ciliaris*, *Dactyloctenium aegyptium*, *Eleusine indica*, and *Ludwigia parviflora*. According to Norman *et al*. (2011), *Cyperus rotundus*, *Talinum triangulare*, *Paspalum conjugatum*, *Digitaria horizontalis*, and other weeds were common in the okra field.

Sharma and Patel (2011) opined that okra was more commonly noticed with grass weeds than with BLW. *Eleusine indica* (L.) Gaertn., *Digitaria sanguinialis* (L.) Scop., and *Dactyloctenium aegyptium* (L.) P. Beauv. were the most common grass weeds found.

2.2.3 Weed induced yield loss in okra

During the rainy season (*kharif*), okra experiences substantial yield losses due to weed infestation. Luxuriant weed growth conditions, such as wider row spacing and slow initial development of okra, contribute to this problem (Patel *et al*., 2004). Weeds adversely affect the crop through various activities, including competition for resources, allelopathic effects, acting as alternate hosts for pests and pathogens, and contaminating farm products. These combined effects have a cumulative impact on crop yield and ultimately lead to significant crop losses. Managing weed infestation during the rainy season becomes crucial to mitigate these negative effects and preserve okra's productivity.

According to Singh *et al.* (1981), weeds caused a substantial reduction of 76.5 per cent in the fresh fruit yield of okra. Other studies have also reported significant yield reductions due to weed interference in okra, ranging from 54.1 to 90.6 per cent (Singh *et al*., 1982). Adejonwo *et al*. (1989) observed an even more severe yield reduction of 88 to 90 per cent in okra fields with uncontrolled weed development. The extent of yield drop in okra is influenced by factors such as the type of weed, weed density, and the duration of weed-crop competition. For instance, Ameena (2003) reported a yield loss of 63.16 per cent in unweeded control plots in okra fields heavily infested with purple nutsedge.

In vegetable-based cropping systems, weed interference has led to significant reductions in okra production, ranging from 85 to 95 per cent (Santos *et al*., 2020 and Bachega *et al*., 2013). These findings highlighted the critical importance of effective weed management strategies to mitigate the adverse effects of weeds on okra yield and overall crop productivity.

2.3 INTEGRATED WEED MANAGEMENT IN OKRA

Frequent use of the same chemical herbicide and repetitive cultivation practices can lead to changes in weed communities over time. Shweta and Singh (2005) noted that integrated weed management (IWM) is a significant strategy aimed at modifying the competitive balance between crops and weeds in favour of the crop. IWM involves the implementation of various weed control methods, such as mechanical, cultural, and chemical approaches, in a coordinated and sustainable manner to effectively manage weed populations and reduce their negative impact on crop growth and yield. By employing multiple strategies, IWM seeks to minimize the development of herbicide-resistant weed species and promote more sustainable and resilient agricultural practices. Weeds predominate during the monsoon season and improper weed management is the main cause for yield loss during rainy season. Apart from lowering yield, weeds reduce the quality of vegetables. Weeds can be managed effectively by integrating chemical and physical approaches. The purpose of IWM is to keep density of weeds under control while giving crops a dominance over weeds (Zimdahl, 2017).

Fertilization has an impact on the competition between crops and weeds, as well as the dynamics of weed communities. In agricultural systems, the timely application of nitrogen (N) fertilizer has been suggested to favour crops in nutrient competition over weeds. Lamichhane *et al*. (2017) stated that integrated weed management, combining multiple techniques, is more effective than using a single method to reduce weed growth in crops. By utilizing all available weed management options, it becomes feasible to maintain the weed population below the economic threshold level (Pooniya *et al*., 2017).

2.3.1 Cultural methods of weed control

The primary purpose of cultural operations is to manage weeds. More than half of the weed management methods designed for farms involve appropriate cultural practices, which directly benefit crops and indirectly create a favourable crop environment (Sathiyavani and Prabhakaran, 2015). According to Daramola *et al*. (2020), hoe weeding three times at 3, 6, and 9 weeks after sowing led to the highest fruit yield in okra during both the early and late wet seasons (3590 and 4102 kg ha^{-1}, respectively).

2.3.2 Hand weeding

The most commonly used method for weed management in okra is hand weeding (HW). However, farmers face challenges with this manual weed control strategy, such as the lack of available workers for weeding at the right time, high labour costs, and expensive production expenses. Despite these difficulties, hand weeding is considered one of the most effective weed control techniques due to its ability to efficiently control weeds (WCE) and improve crop yield.

Reddy *et al*. (2001) reported that the highest weed control efficiency (WCE) was achieved with hand weeding (HW) conducted twice at 25 days after sowing (DAS) and 40 DAS. On the other hand, Kumara *et al*. (2007) stated that herbicides are more economical and cost-effective for managing weeds during the initial stages compared to hand weeding. Despite its effectiveness, hand weeding becomes impractical due to challenges such as the unavailability of labour at the right time, high labour costs, and adverse environmental conditions (Singh, 2008). These factors may hinder the practical application of hand weeding in weed management practices.

2.3.2.1 Effect on weed parameters

Dutta *et al*. (2016) observed that hand weeding led to a reduction in weed biomass and achieved a higher weed control efficiency of 88.3 per cent in okra. According to Sakshi *et al*. (2016), hand weeding conducted at 15 days after sowing (DAS) and 30 DAS resulted in the highest weed control efficiency (97.67%). Similarly, Sah *et al*. (2018) observed lower weed density in okra when hand weeding was performed twice at 20 and 40 DAS. These studies highlighted the effectiveness of hand weeding in managing weeds and improving weed control efficiency in okra cultivation.

Kalhapure *et al*. (2013) observed that three HW at 20, 40, and 60 days after transplanting resulted in decreased weed densities, reduced dry weight of weeds, and improved weed control efficiencies, leading to higher growth and yield parameters in onion. According to Baraiya *et al*. (2017), performing two HW at one and two months after sowing in okra resulted in the least number of weeds and the highest weed control efficiency (97.67%).

Madhukia et al. (2018) indicated that hand weeding was highly successful in reducing weed biomass and density, as well as lowering the weed index (WI) in okra. These studies demonstrated the efficacy of hand weeding as a viable weed management practice in improving crop growth and yield in both onion and okra cultivation.

2.3.2.2 Effect on growth and yield parameters

Zinzala *et al*. (2017) observed that hand weeding conducted three times at 20, 40, and 60 days after sowing (DAS) significantly increased the fruit yield of okra. Patel *et al*. (2017) found that manual weeding performed three times at 20, 40, and 60 DAS resulted in higher weed control efficiency and fruit yield compared to chemical treatments. Narayan *et al*. (2020) reported the highest yield of okra in plots where two to three HW were performed.

According to Kujur *et al*. (2015), hand weeding resulted in the highest nutrient uptake for cowpea and the lowest nutrient loss caused by weeds. In another study, taller plants, a greater number of branches, and more leaves at harvest were observed in okra that underwent HW twice, at one and two months after planting, as reported by Baraiya *et al*. (2017). These findings highlighted the positive impact of hand weeding on crop yield, weed control, and nutrient uptake in okra and cowpea cultivation.

2.2.2.3 Effect on economic parameters

To gain acceptance among farmers, weed management technologies need an economic assessment, considering both cost-effectiveness and improved weed control efficiency (WCE). Hand weeding has been a traditional practice in Indian farming, proving effective against annual weeds but less so against perennial weeds due to their regenerative capabilities. Due to rising labour costs and scarcity, farmers now prefer herbicidal application, either alone or in conjunction with hand weeding, to address weed challenges efficiently.

In studies conducted by Patil and Reddy (2014), Kujur *et al*. (2015), and Zinzala *et al*. (2017), hand weeding proved to be a financially advantageous weed management strategy. In vegetable cowpea, two HW at 25 and 45 days after sowing (DAS) resulted in a higher net revenue of ₹49,332 ha^{-1} and a B:C ratio of 1.63 (Patil and Reddy, 2014). Similarly, in cowpea, maximum net revenue was achieved with hand weeding performed twice at 20 and 40 DAS (Kujur *et al*., 2015). Zinzala *et al*. (2017) also reported higher net income in okra, where three HW at 20, 40, and 60 DAS generated a net income of ₹1,05,233 per ha. These findings highlighted the economic viability of hand weeding as an effective weed management technique in various crops.

2.3.2 Chemical weed management

The chemical approach to weed control provides favourable conditions for the early growth and development of crops. This method proves effective in managing weeds with similar morphology, those growing inside rows, and problematic weeds, among others. In okra, herbicides applied in sequence, both pre- and post-emergence, demonstrated better weed control compared to pre-emergence application alone (Patel *et al*., 2017).

In India, approximately 6000 tonnes of herbicides are utilized for weed management, with a significant portion (77%) being applied to irrigated crops like wheat and rice, and around 10 per cent on plantations. However, the overall herbicide usage in India constitutes only 12% of the total (Saksena, 2003; Bhat and Chopra, 2006). This indicates that chemical weed control is a common practice, particularly in specific crop types, but its overall usage is relatively limited in the country.

Brar and Walia (1989) conducted an estimation that chemical weed control proves highly effective and can increase crop yields by 52-84 per cent compared to unweeded control, depending on the type of crop. Miller and Libby (1999) and Ali *et al*. (2003) also recommend herbicidal weed control to enhance maize production. According to Hassan *et al*. (2010), herbicidal treatment is considered one of the most successful weed management methods for maize cultivation. These studies underline the significant positive impact of herbicidal weed control on crop yields, particularly in maize production.

2.3.2.1 Pendimethalin

Shamla *et al*. (2017) found that applying pendimethalin pre-emergence in okra led to reduced weed population and dry matter production during the initial stages of the crop. However, the weed population and dry matter increased as the crop grew. Sah *et al*. (2018) reported that the maximum crop growth parameters and yield attributes of okra were recorded with pendimethalin 30EC at a rate of 1.5 kg ai ha^{-1} along with one hand weeding during the crop growth period. These studies highlighted the effectiveness of pendimethalin in managing weeds and enhancing crop growth and yield in okra cultivation.

Saimbhi *et al*. (1994) opined that applying pendimethalin at a rate of 0.75 kg ha^{-1} resulted in superior weed control efficacy in okra. Pendimethalin has demonstrated its effectiveness as a weed control agent in okra, whether used alone or in combination with broadleaf herbicides, and in conjunction with other weed control techniques, particularly HW (Dhanapal and Gowda, 1996). For brinjal, Syriac and Geetha (2007) found that alachlor at 2-2.5 kg ha^{-1}, oxadiazone at 0.5-0.75 kg ha^{-1}, pendimethalin at 25 kg ha^{-1}, and two HW provided effective weed control.

The application of pre-emergence pendimethalin and pre-planting fluchloralin at a rate of 1 kg ha^{-1} resulted in significant improvements in various growth and yield parameters of French beans. These improvements included increased plant height, number of branches, dry matter accumulation, number of pods per plant, number of seeds per pod, seed yield, and straw yield (Panotra *et al.,* 2012). According to Sharma *et al*. (2014), pendimethalin showed to be effective in abolishing weeds like. *Dactyloctenium aegyptium* and *Digitaria sanguinalis*.

The combined application of pre-emergent herbicide pendimethalin at a rate of 1.05 kg ha^{-1}, followed by post-emergent herbicide quizalofop ethyl at a rate of 0.04 kg ha^{-1} at 30 days after sowing (DAS), effectively suppressed weeds in okra crop (Patel *et al*. (2022). This approach resulted in a weed control efficiency of 71.3 per cent. By adopting this method, farmers not only reduced the physical labour involved in manual weed removal but also found it to be a practical and economically viable option for weed management, leading to increased yield of okra.

2.3.2.1.1 Effect on weed parameters

Pendimethalin, applied at 1.25 kg ha^{-1} before weed emergence, either alone or combined with one hoeing at 45 days after transplanting, effectively reduced weed population, weed dry weight, and weed nutrient uptake, resulting in the best yield of chilli (Kumar *et al.,* 1995). Similarly, applying pendimethalin at 1.0 kg ha^{-1} with mulching in onion cultivation led to a lower weed population of 67.90 m^{-2} (Priyadharshini and Anburani, 2004).

2.3.2.1.2 Effect on yield parameters

For maximizing yield and economic returns in okra, the most effective weed control method involved spraying pendimethalin at 3 L ha^{-1} as a pre-emergence treatment, followed by one hand weeding at 45 days after sowing (Singh *et al*., 2010). Similarly, in onion cultivation, the best outcomes were achieved by applying pendimethalin at 1 kg ha^{-1} in combination with mulching, resulting in the highest yield, lowest weed dry matter, and reduced weed population (Priyadharshini and Anburani, 2004).

2.3.2.1.3 Effect on economics

Channappagoudar *et al*. (2013) found that applying pendimethalin at 1.5 kg ha^{-1} resulted in the highest benefit-to-cost ratio among the tested herbicides in turmeric. The benefit-to-cost ratio was 2.13 for pendimethalin at 1.5 kg ha^{-1}, followed by 2.10 for the application at 1.0 kg ha^{-1} in turmeric, as reported by Babu (2008).

In a study conducted by Gowsalya *et al*. (2010), pre-emergence .pendimethalin at 0.75 kg ha^{-1} at 3 DAS followed by one weeding with a wheel hoe weeder at 45 DAS or pre-emergence. pendimethalin application at 0.75 kg ha^{-1} at 3 DAS followed by one weeding with a wheel hoe weeder at 45 DAS both provided effective and affordable weed control in rainfed pigeonpea. According to an economic analysis by Patel *et al*. (2011), pendimethalin at 1.0 kg ha^{-1} + HW at 40 DAT resulted in a higher net profit (2,69,422 ha^{-1}) with a B:C ratio of 7.85 in onion crops than oxyfluorfen at 1.0 kg ha^{-1} + HW at 40 DAT and weed-free control (2,51,910 ha^{-1}). Sathya Priya *et al*. (2013) opined that pre-emergence pendimethalin application at 0.75 kg ha^{-1} combined with rotary weeding on 45 DAS resulted in higher gross and net returns.

2.3.2.2 Oxyfluorfen

Sheikh (2005) concluded that hand weeding, supplemented with oxyfluorfen 0.1 kg/ha and pendimethalin 0.75 kg ha^{-1}, had a weed control efficacy of more than 80 per cent. The best method for managing annual weeds in cabbage was to apply oxyfluorfen at a rate of 0.2 kg ha^{-1} 30 days after transplanting, along with one hand weeding (Nandanwar *et al*., 2006). Jalendhar (2010) reported that among the different weed management practices, application of oxyfluorfen as pre-emergence at 0.15 kg ha^{-1} + one hand weeding at 30 DAS recorded significantly the higher weed control efficiency.

2.3.2.2.1Effect on weed parameters

Kolhe (2001) reported that the use of oxyfluorfen either alone or in combination with hand weeding at 35 days after planting resulted in a considerable reduction in the dry matter of weeds as compared to weedy check in onion. Oxyfluorfen is a highly powerful herbicide appropriate for weed destruction in onion and cabbage, and it is being sprayed frequently for the removal of weeds (Stall and Gilreath, 2002). Sharma and Khandwe (2008) witnessed lower weed population and dry weight of weeds m^{-2} with oxyfluorfen at 1.25 kg ha^{-1}.

2.3.2.2.2 Effect on yield parameters

As reported by Ranpise and Patil (2001), pre-emergence application of oxyfluorfen at 0.4 kg ha^{-1} produced the highest yield in onion (242.2 q ha^{-1}), followed by 0.2 kg ha^{-1} (233.3 q ha^{-1}) in comparison to the lesser yield under control (50 q ha^{-1}) because of the highest weed intensity. The oxyfluorfen-treated plots had increased fresh bulb weight and bulb diameter, according to Saini and Walia (2012).

2.3.2.2.3 Effect on economics

Nandal and Singh (2002) noticed a higher net return when oxyfluorfen at 0.25 kg ha^{-1} was combined with hand weeding at 40 DAT (60,196 ha^{-1}), followed by oxyfluorfen at 0.75 kg ha^{-1} (54,978 ha^{-1}). Pre-emergence application of oxyfluorfen at 0.25 kg ha^{-1}, followed by post-emergence application of quizalofop ethyl at 0.05 kg ha^{-1}, and two hand weedings at 60 and 90 DAS recorded significantly higher fresh rhizome yield of turmeric with a benefit:cost ratio of 0.61 and was comparable to hand weeding at 30, 60, and 90 DAS (Ratnam *et al*., 2012). Oxyfluorfen application resulted in greater net return for onions (1,85,600) with a B:C ratio of 7.63 (Saini and Walia, 2012).

In response to Mondal *et al*. (2005) higher net monetary returns were acquired with pre-emergence application of oxyfluorfen at 100 g ha^{-1} supplemented with one hand weeding on 25 DAT (33,650 ha^{-1}). This was followed by fluchloralin at 750 g ha^{-1} + hand weeding (31,983 ha^{-1}), pendimethalin at 750 g ha^{-1} + hand weeding (31,450 ha^{-1}) and oxyfluorfen at 200 g ha^{-1} (31,400 ha^{-1}). Under the weedy check, there was a net loss of 3,900 ha^{-1}.

2.3.4 Effect of nitrogen fertilization and hand weeding

According to Mahajan and Timsina (2011), when the crop was supplemented with 150 kg of N per hectare along with pendimethalin + 1 HW, as opposed to 120 kg per hectare, weeds produced 44.7 per cent more dry matter. On the other hand, Ahmed *et al*. (2015) found that an increase in N rate from 0 to 80, 80 to 120, and 120 to 160 kg ha^{-1} resulted in yield increases of 42, 13, and 12 per cent in hand weeded plots. Similarly, Dalga (2016) reported that the maximum grass weed dry weight was observed in the combination with the weedy check with zero N ha^{-1}, while the lowest grass weed dry weight was recorded in combinations of two hand weeding at 2 and 5 weeks after emergence with 110 kg N ha^{-1}.

2.3.5 Effect of nitrogen fertilization and herbicides

According to El-Metwally *et al*. (2010), the application of isoproturon + diflufinican significantly reduced the total dry weight of barley weeds when 15 kg N was applied. However, adding 60 kg of nitrogen per feed in the unweeded treatment led to the highest total dry weight of barley weeds. Similarly, under the 60 kg N and isoproturon + diflufinican treatment, the highest number of spikes per square meter, grain weight per spike, grain and straw yields, and other metrics were reported. Conversely, when 15 kg N was supplied in the unweeded treatment, the lowest spikes per m^2, grain weight per spike, grain, and straw yields were observed.

2.3.6 Effect of herbicides and hand weeding

Pre-emergent herbicides play a crucial role in keeping the crop weed-free during the early stages, especially when combined with one or two hand weeding operations. Hand weeding becomes less costly in later stages, making it a practical approach throughout the crop growing cycle to maintain the weed population below the economic threshold level (Shivalingappa *et al.,* 2014).

According to Leela (1993), pendimethalin, which provided weed control for up to 30 days, was shown to be effective in short-duration crops such as amaranthus, peas, and beans only. For successful weed management in long duration vegetable crops, she claimed that pendimethalin followed by one-handed weeding was the best course of action. According to Nagar *et al*. (2009), the most efficient and cost-effective approach of weed management is the combination of hand weeding with herbicides.

Moolchand *et al.* (2010) observed higher efficacy of pre-emergence pendimethalin 30 EC at 3 L ha^{-1} followed by hand weeding at 45 DAS compared to sole pre-emergence application of pendimethalin. The hand hoeing technique that resulted in the greatest weed reduction was either given twice or applied once along with post-emergent herbicides (Kandil and Kordy, 2013). Pre-emergence herbicides keeps the weed population below the economic threshold during the early crop growth stages whereas a follow up hand weeding gives effective weed management at later stages of crop (Shivalingappa *et al*., 2014).

Combining herbicides with hand weeding proves to be a less laborious, cost-effective, and promising option compared to hand weeding alone at specific intervals. In the case of okra, pendimethalin at 1.5 kg ha^{-1} followed by hand weeding at 40 DAS showed lower weed dry weight compared to hand weeding done twice. This improved efficacy may be attributed to the dissipation and deactivation of the pre-emergence herbicides in the soil, rendering them ineffective after a certain period of weed management.

Based on the literature review, an inference could be made that foliar application of nano-N offers various advantages over conventional fertilizers, particularly in terms of growth and weed parameters. Nano-N enhances fertilizer efficiency, reduces nutrient wastage, and improves nutrient absorption. Additionally, weed management practices such as hand weeding and the use of herbicides like pendimethalin and oxyfluorfen have been found to be beneficial in controlling weed growth while increasing crop productivity and economic returns. Therefore, the combination of foliar application of nano-N and effective weed control methods can be recommended as an integrated weed management strategy for okra cultivation.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study entitled “Integrating weed management with nano nitrogen in okra (*Abelmoschus esculentus* (L.) Moench)” was carried out at Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram district, Kerala during January 2022-April 2022. The objective of the experiment was to formulate an integrated weed management strategy based on nitrogen management using nano nitrogen to reduce crop weed competition in okra. The materials used and the methods followed for the conduct of research work are described below.

3.1. GENERAL DETAILS

3.1.1 Location

The field experiment was conducted at the E block of Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India. The experimental field was geographically located at $8^{o}29^{'}40.9^{''}$ N latitude and $76^{o}59^{'}14.1^{''}$ E longitude, at an altitude of 5 m above mean sea level.

3.1.2 Climate and season

The experiment was carried out during the rabi season of 2021 between December to April 2022. Weather data on maximum and minimum temperatures, relative humidity, and rainfall were collected from the Class B Agromet Observatory of the Department of Agricultural Meteorology, College of Agriculture, Vellayani. The data were tabulated based on the standard meteorological weeks and are presented in Appendix I and graphically in Fig.1.

In general, sunny, warm conditions prevailed during the cropping period. The mean maximum and minimum temperature ranged between 31.9^{o}C to 33.9^{o} C and 20.9^{o}C to 25.3^{o}C respectively and mean RH I and RH II ranged between 87.7 per cent to 93.9 per cent and 74.3 per cent to 89.3 per cent, respectively with a mean evaporation of 3.77 mm per day. Mean bright sunshine hours varied from 4.3h to 9.1h. A total rainfall of 74.6 mm was received during the experimental period.

3.1.3 Soil

The soil of the experimental site belongs to the soil order oxisol with sandy clay loam texture. Composite soil sample was taken prior to the experiment from the field and tested for its physico-chemical properties. The physico- chemical composition of the soil of the experimental field is presented in Table 1a and 1b.

Table 1a. Mechanical composition of soil of the experimental site

Sl No.	Fraction	Content in soil (%)	Method adopted
1	Coarse sand	45.51	Bouyoucos Hydrometer method (Bouyoucos, 1962)
2	Fine sand	10.75	
3	Silt	8.42	
4	Clay	35.32	

Table 1b. Chemical properties of soil of the experimental site

Sl. No	Parameter	Content	Rating	Method adopted
1	Soil reaction (pH)	5.65	Moderately acidic	1:2.5 soil solution ratio .using pH meter (Jackson, 1973)
2	Electrical conductivity (dS m^{-1})	0.22	Normal	1: 2.5 soil solution ratio using conductivity bridge (Jackson, 1973)
3	Organic carbon (%)	1.11	Medium	Walkley and Black rapid titration method (Walkley and Black, 1934)

Plate 1. Land preparation and layout of the field

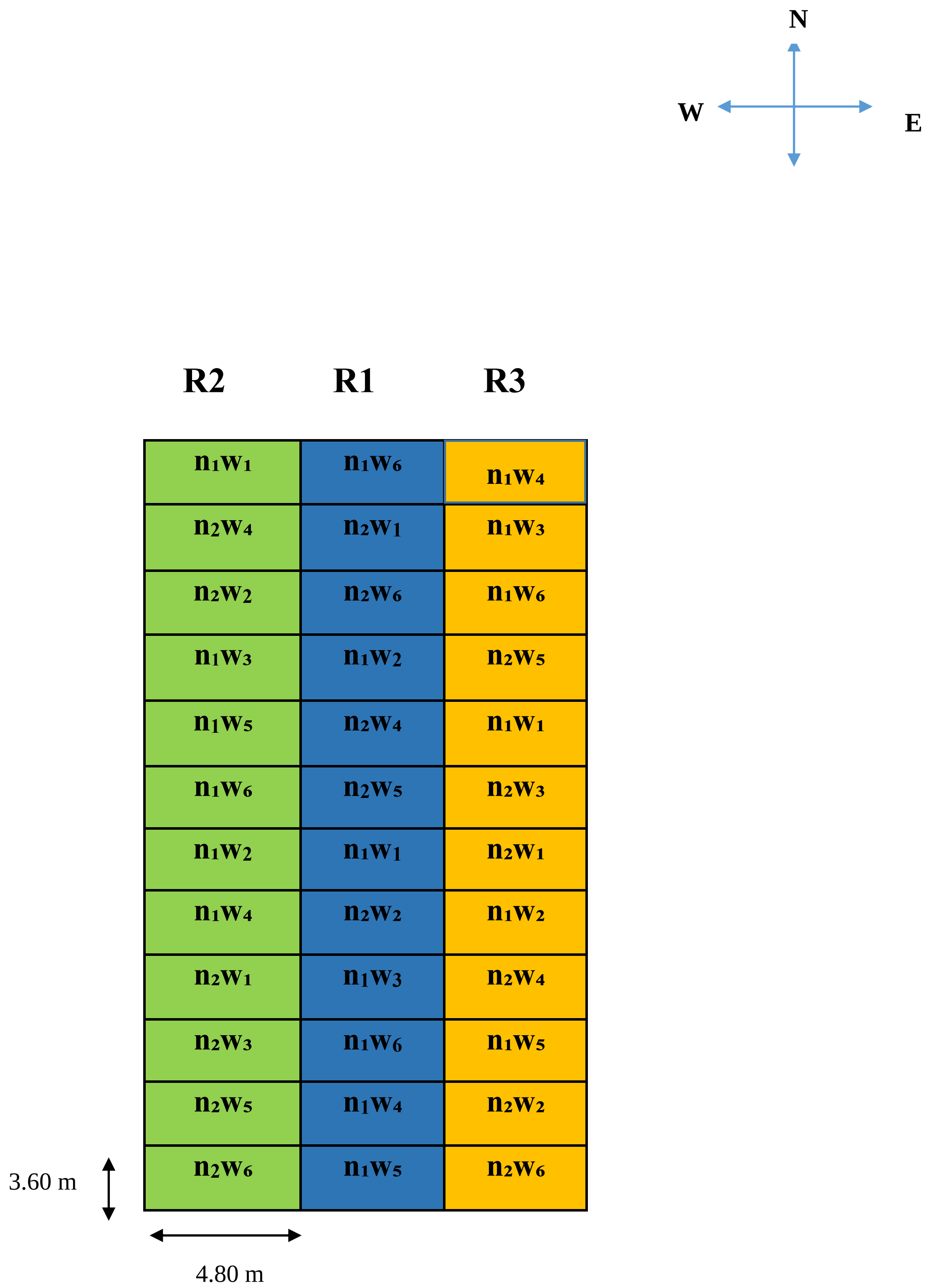

Fig 2. Layout of the experimental field

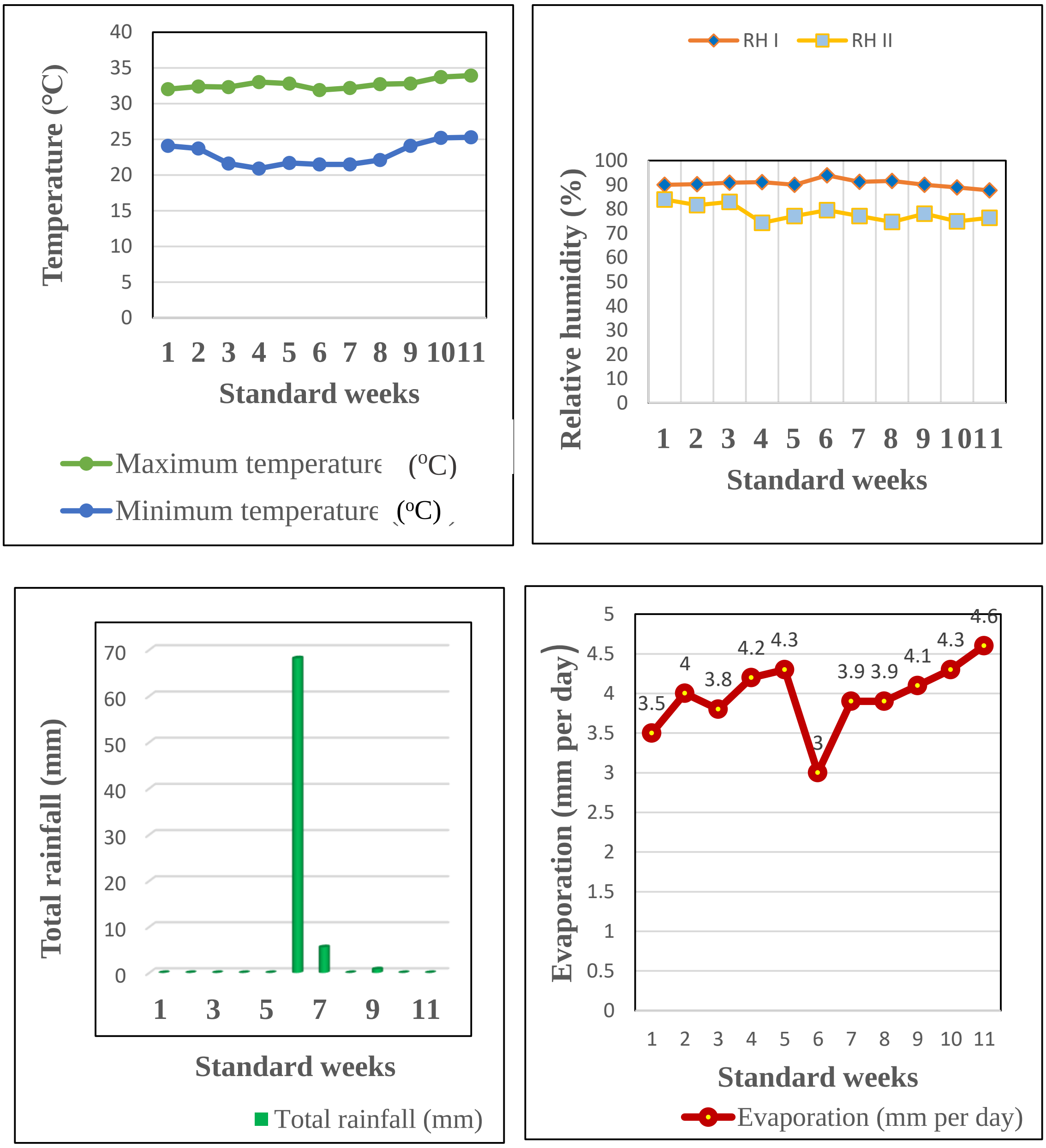

Fig. 1. Weather data during the crop season (10/01/2022 to 28/03/2022).

4	Available N (kg ha^{-1})	204.72	Low	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg ha^{-1})	292.14	High	Bray colorimetric method (Jackson,1973)
6	Available K (kg ha^{-1})	198.26	Medium	Ammonium acetate method (Jackson, 1973)

3.1.4 Cropping history

Previously, a crop of brinjal was grown at the experimental site for research purpose.

3.2 MATERIALS

3.2.1 Crop Variety

Anjitha, a high yielding and yellow vein mosaic resistant variety having a duration of 120 days released from Department of Plant Breeding and Genetics, College of Agriculture, Vellayani was used as the test crop.

3.2.2 Source of Seed

The okra seeds of Anjitha variety were purchased from the Instructional Farm, College of Agriculture, Vellayani.

3.2.3 Manures and Fertilizers

Dried cow dung powder from Instructional Farm was used as organic manure. Urea and IFFCO nano urea were given as sources of nitrogen (N); Rajphos and Muriate of potash were given as sources of phosphorus (P) and potassium (K), respectively.

3.2.4 Herbicides

The herbicides used in the experiment were pendimethalin and oxyfluorfen. The toxicity, technical information and other available data of the herbicides pendimethalin and oxyfluorfen are given in Table 2.

3.3 METHODS

3.3.1 Design and layout

Design	: RBD
Replications	: 3
Treatments	: 2 x 6 =12
Season	: *Rabi* 2021-22
Spacing	: 60 cm x 45 cm
Gross plot size	: 4.8 m x 3.60 m
Net plot size	: 3.6 m x 2.70 m
Location	: Instructional Farm, Vellayani

Table 2: Technical information of the herbicides used in the study

Common name	Pendimethalin	Oxyfluorfen
Chemical name	N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene
Chemical group	Dinitroanilines	Diphenyl ethers
Molecular formula	$C_{13}H_{19}N_3O_4$	$C_{15}H_{11}ClF_3NO_4$
Trade name	Stomp	Goal
Formulation	30% EC	23.5% EC
Physical state, colour and odour	Yellowish crystalline liquid, faint nutty or fruit like odour	Crystalline liquid, orange to deep red brown, odourless
Acute oral toxicity LD_{50}(rat)	>1050 mg kg^{-1}	> 5000 mg kg^{-1}
Manufacturer	BASF	Dow Agro Chemicals

Plate 2. General view of the field after land preparation, 15 DAS and 30 DAS

Plate 3. Pre emergence herbicide application and nano urea spraying

Price (₹)	669 (1L)	230 (100 mL)

3.3.2 Treatment details

Factor A: Nitrogen Management (N)

n_1 – 50 per cent recommended dose of nitrogen (RDN) as urea in soil (basal dose) + Nano N as 0.2 per cent nanourea spray at 20 and 40 days after sowing (DAS)

n_2 – 100 per cent N as urea as per KAU POP

Factor B: Weed Management Practices (W)

w_1- Pre emergence application of pendimethalin at 1 kg ha^{-1}

w_2- Pre emergence application of oxyfluorfen at 0.15 kg ha^{-1}

w_3- Pre emergence application of pendimethalin at 1 kg ha^{-1} *fb* hand weeding at 30 DAS

w_4- Pre emergence application of oxyfluorfen at 0.15 kg ha^{-1} *fb* hand weeding at 30 DAS

w_5- Hand weeding at 15 and 30 DAS

w_6- Weedy check

(KAU POP- FYM @ 20 t ha^{-1}; NPK- 110:35:70 kg ha^{-1}) (*fb*- followed by)

Treatment combinations:

n_1w_1, n_1w_2, n_1w_3, n_1w_4, n_1w_5, n_1w_6,

n_2w_1, n_2w_2, n_2w_3, n_2w_4, n_2w_5, n_2w_6

The treatments were randomly allotted in each replication using random numbers.

3.3.3 Preparatory cultivation

After selecting the experimental site, the experimental area was cleared with the help of a tractor. The stubbles were removed and the land was leveled and made into a fine tilth by using power tiller. The entire experimental area was then divided into 36 treatment plots each with a gross plot size of 4.8 m x 3.60 m. Bunds of 30 cm width were taken around each plot.

3.3.4 Lime Application

Lime at the rate of 250 kg ha^{-1} was uniformly applied to the plots at the time of final ploughing and the field was raked immediately.

3.3.5 Manures and fertilizers application

Dried powdered cowdung at 20 t ha^{-1} was uniformly applied to all the treatment plots. P and K at 35 and 70 kg ha^{-1} respectively were given to all plots as basal dose. Basal dose of nitrogen (55 kg N ha^{-1}) was applied as urea in soil uniformly for all the treatments plots. Remaining dose of nitrogen was given as per the treatments either as urea application in soil or as nano N through 0.2 per cent nano urea spray at 20 and 40 DAS. The crop was grown and managed in line with the cultivation practices as per the recommendations of Package of Practices (KAU, 2016).

3.3.6 Seeds and sowing

A seed rate of 8 kg ha^{-1} and spacing of 60 cm x 45 cm were adopted and okra seeds were dibbled at three seeds per pit on 10/01/2022. The field was irrigated immediately after sowing to assure uniform germination.

3.3.7 After cultivation

Gap filling and thinning were carried out 2 WAS to maintain.uniform plant. population with 2 seedlings per pit.

3.3.8 Weed management

Weed management practices were done according to the treatment schedule. The amount of spray volume utilized was 500 L ha^{-1}. Manually operated knapsack sprayer fitted with a flat fan nozzle was used for herbicide spraying. Pre-emergence application of herbicide was done on the next day of sowing followed by hand weeding at 30 DAS. In weed free check, hand weeding was done at 15 and 30 DAS and weedy check plot maintained free of weed control practices.

3.3.9 Plant protection

Flubendiamide @ 2 mL 10L^{-1} was sprayed for controlling the infestation of leaf eating caterpillars at 18 DAS and chlorantraniliprole @ 3 mL 10 L^{-1} was used for controlling the fruit and shoot borer at 60 DAS.

3.3.10 Harvest

The fruits were harvested once in two days from 43 DAS to 91 DAS. A total of 15 harvests were taken. Fruit yield from the observation plants and fruit yield from the net plot area were recorded treatment wise.

3.4 OBSERVATION ON CROP

3.4.1 Growth Parameters

Three plants were randomly tagged in each treatment plot from the net plot area as observation plants after excluding the border row, for recording the observations on growth and yield parameters.

3.4.1.1 Plant Height

Plant height was measured from the three observation plants at 30 and 60 DAS and at final harvest. Plants were measured from the ground to the tip of the uppermost leaf and average plant height was calculated and expressed in cm.

3.4.1.2 Number of Leaves per Plant

Number of leaves in the tagged observation plants were counted at 30, 60 DAS and at final harvest. The average was calculated and expressed as number per plant.

3.4.1.3 Number of Branches per Plant

From the tagged plants, number of branches per plant were counted at 30, 60 DAS and at final harvest and the mean values were worked out.

3.4.1.4 Dry Matter Production (DMP) per Plant

At final harvest, two randomly selected plants were uprooted from each treatment plot from the net plot area avoiding one row of border plants. The plant samples were shade dried for two days and then oven dried at 65 ± 5 °C till constant weight was attained. The average was worked out and expressed as gram per plant.

3.4.1.5 Leaf Area Index

The leaf area of bhindi leaves were measured at 20 DAS and 40 DAS. Linear method (length x breadth) was used and the value was expressed in cm^2.

Leaf area =Lx B x K x n

Where,

L= Length of leaf, cm

B= Breadth of leaf, cm

K= Constant value (0.65)

n = Number of leaves per plant

Then LAI was calculated based on the recorded leaf area per plant by using theformula,

$$\text{LAI} = \frac{\text{Leaf area of plant (cm}^2)}{\text{Land area occupied by plant (cm}^2)}$$

3.4.2 Yield and Yield Components

For computing the yield parameters, three plants in the net plot area were identified and tagged as observation plants.

3.4.2.1 Days to 50 per cent Flowering

Days to 50 per cent flowering was recorded by counting the number of days taken from sowing to 50 per cent flowering in each treatment plot and expressed in days.

3.4.2.2 Number of Fruits per Plant

The number of fruits from the tagged observation plants were counted at each harvest. The average was calculated and expressed as number of fruits per plant.

3.4.2.3 Fruit Length

Three fruits from each treatment plot were randomly selected from the observation plant on each harvest for measuring the fruit length. Fruit length was measured from base to the tip of the fruit, the average was worked out and expressed in cm.

3.4.2.4 Fruit Weight

The average weight of a fruit was calculated from the fruits obtained from each treatment plot and expressed in g.

3.4.2.5 Fruit Yield per Plant

Fruits from the tagged observation plants were collected at each harvest and weighed. The average was worked out to compute the fruit yield per plant and expressed in g.

3.4.2.6 Fruit Yield per Hectare

Fruit weight from each harvest from the net plot area were recorded, pooled and expressed in kg ha^{-1}.

3.4.2.7 Haulm Yield per Plant

The observation plants were uprooted from each treatment plot after harvest, sun dried and weighed individually, the average was worked out and denoted as g per plant.

3.4.2.8 Haulm Yield

The plants were uprooted from the net plot area of each treatment after the final harvest, they were sun dried and weighed. Total haulm yield was computed from the haulm yield obtained from the net plot area and it was expressed in kg ha^{-1}.

*3.4.2.9 Harvest*Index*

The harvest index was assessed using the formula proposed by Donald and Hamblin (1976).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.2.10 Weed Index (WI)

Weed index was calculated using the formula suggested by Gill and Vijayakumar (1969)

$$WI = \frac{X - Y}{X} \times 100$$

Where,

X- Yield from the treatment which recorded the minimum number of weeds

Y- Yield from the plot for which WI was to be determined

3.5 OBSERVATION ON WEEDS

3.5.1 Weed Flora

At 15, 30 and 45 DAS, various weed species observed in the experimental area were identified and enlisted.

3.5.2 Weed Density

Weed counts from each treatment plot were taken at 15, 30, and 45 DAS using a quadrat of size 50cm x 50 cm. At every stage of the sampling, weeds were categorized into grasses, sedges and broad leaf weeds and expressed as number m^{-2}.

3.5.3 Weed Dry Weight

The weeds were uprooted from the same area where 0.25 m^2 quadrat was placed, at 15, 30 and 45 DAS, they were dried under shade for two days, followed by oven drying at 65± 5°C to attain a constant weight and then it was expressed in g m^{-2}, at all the stages of observation.

3.5.4 Weed Control Efficiency

Weed control efficiency was worked out by the formula put forth by Mani and Gautham (1973)

$$WCE = \frac{WDWC - WDWT}{WDWC} \times 100$$

Where,

WCE - weed control efficiency

WDWC - weed dry weight in control plot (weedy check), in the present experiment n_2w_6 considered as the weedy check

WDWT - weed dry weight in treated plot

3.5.5 Relative Weed Density

The relative weed density of grasses, sedges, and broadleaf weed (BLW) were calculated at 15, 30, 45 and 60 DAS using the formula put forth by Philips (1959).

$$Rd = \frac{\text{Absolute density of a species}}{\text{Total absolute density of all species}} \times 100$$

3.5.6 Relative Weed Biomass

The oven dry weight of specific weed group to that of total weed flora dry weight was analyzed and expressed in percentage at 15, 30, 45 and 60 DAS.

3.6 PHYSIOLOGICAL PARAMETERS

3.6.1 Total Chlorophyll content

Total chlorophyll content of the leaves was worked out at 30 and 60 DAS by using the protocol developed by Yoshida *et al*. (1976).

3.6.2 Nitrogen Use Efficiency

Nitrogen use efficiency was evaluated using different parameters like agronomic efficiency, physiological efficiency and apparent recovery efficiency. They were calculated as per the formula suggested by Fageria and Baligar (2005).

3.6.2.1 Partial Factor Productivity (PFP)

Partial factor productivity of nitrogen was calculated as the ratio between fruit yield (Y) and the quantityvof nitrogen applied (A) and expressed as kg yield kg^{-1} nitrogen applied.

$$PFP = \frac{Y}{A}$$

3.6.2.2 Agronomic Efficiency (AE)

The following formula was used for determination of agronomic efficiency and it is expressed as kg fruits per kg nutrient applied.

$$AE = \frac{Y_f - Y_u}{N_a}$$

Where,

Y_f = Fruit yield of the fertilized plot (kg)

Y_u = Fruit yield in control plot (kg)

N_a = Quantity of nitrogen added (kg)

3.6.2.3 Physiological Efficiency (PE)

Physiological efficiency was evaluated using the following formula and expressed as kg yield increase per kg nutrient uptake.

$$PE = \frac{Y_f - Y_u}{N_f - N_u}$$

Where,

Y_f = Fruit yield of the fertilized plot (kg)

Y_u = Fruit yield in control plot (kg)

N_f = Total nutrient uptake in the fertilized plot (kg)

N_u = Total nutrient uptake in the control plot (kg)

3.6.2.4 Apparent Recovery Efficiency (ARE)

Apparent recovery efficiency was assessed based on the following formula and expressed in percentage.

$$ARE = \frac{N_f - N_u}{Ns}$$

Where,

N_f = Total nutrient uptake in the fertilized plot (kg)

N_u = Total nutrient uptake in the control plot (kg)

Ns = Quantity of nutrients added (kg)

3.7 QUALITY PARAMETER OF FRUIT

3.7.1 Crude Protein Content

Protein content of fruit was determined by the method developed by Simpson *et al*. (1965) and expressed in percentage.

3.7.2 Crude Fibre Content

Crude fibre content of the fruits was determined as per the method suggested by Sadasivam and Manikam (1996) and expressed in percentage.

3.7.3 Ascorbic Acid Content

Ascorbic acid content of the fruits was determined as per volumetric method proposed by Sadasivam and Manikam (1992) and it was expressed in mg per 100g.

3.8 ENZYME ANALYSIS

Dehydrogenase and urease enzyme assay were carried out at 15, 30 and 45 DAS. For analysis, soil samples were collected at 15 cm depth near the rhizosphere region, from each treatment plot area, stored in polythene bags and analysis was completed within a week.

3.8.1 Dehydrogenase Activity

The dehydrogenase activity in soil was determined at 15, 30 and 45 DAS by the method suggested by Cassida *et al*. (1964) and expressed as μg triphenyl formazon (TPF) g^{-1} soil per day.

3.8.2 Urease Activity

The urease activity in soil was determined at 15, 30 and 45 DAS by the method suggested by Watts and Crisp (1954) and expressed as μg urea hydrolyzed g^{-1} soil $4h^{-1}$

3.9 CHEMICAL. ANALYSIS

3.9.1 Nutrient Uptake by Crop and Removal by Weed

Weed and crop composite plant samples were obtained from every plot both during harvest. These samples were dried, ground to a fine powder, and then used to estimate the amounts of nitrogen, phosphorus, and potassium using the methods described by Jackson (1973). By multiplying the various nutrient contents by the corresponding dry weights, the uptake of nitrogen, phosphorus, and potassium by the crop and any associated weeds at harvest was estimated and expressed as kg ha^{-1}.

3.9.2 Soil Analysis

Before the experiment began and after the crop was harvested, composite soil samples were taken from the experimental area from each treatment plot. These underwent analysis to determine their N, P, and K contents.

3.9.2.1 Available N

Alkaline potassium permanganate method (Subbaiah and Asija, 1956) was used for the determination of available N and it was expressed in kg ha^{-1}.

3.9.2.2 *Available P*

Dickman and Bray molybdenum blue method (Jackson, 1973) was used for the determination of available P and it was expressed in. kg ha^{-1}.

3.9.2.3 Available K

Flame photometry (Jackson, 1973) was used for the determination of available K and it was expressed in kg ha^{-1}.

3.10 PEST AND&DISEASES

Mild incidence of leaf eating caterpillars and fruit borer were observed. during the crop period. Plants were severely affected by yellow vein mosaic virus during the latter stage of crop period. Recommended management practices were adopted to check the incidence below the economic threshold level.

3.11 ECONOMIC ANALYSIS

3.11.1 Net income

After computing the cost of cultivation and gross income, the net returns obtained was found out using the formula:

Net income (₹ ha^{-1}) = Gross income- cost of cultivation

3.11.2 Benefit: Cost Ratio (BCR)

B:C ratio of the treatments were calculated using the formula

$$BCR = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.12 STATISTICAL ANALYSIS

The experimental data generated were analyzed statistically by applying the technique of analysis of variance (ANOVA) for Randomized Block Design experiment and ANOVA and the significance was tested by F test (Cochran and Cox, 1965). Critical difference (CD) is provided wherever the F test was significant.

RESULTS

4. RESULTS

Field experiment of the research work entitled "Integrating weed management with nano nitrogen in okra (*Abelmoschus esculentus* (L.) Moench)" was carried out at Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram district, Kerala during January to April 2022 with an objective to formulate an integrated weed management strategy based on nitrogen management using nano nitrogen to reduce crop weed competition in okra. The data obtained were statistically analysed and results are detailed in the chapter.

4.1 OBSERVATIONS ON CROP

4.1.1 Growth Parameters

4.1.1.1 Plant Height

Results on the effect of nitrogen management, weed management and their interaction on plant height at 30, 60 DAS .and at harvest are presented in Tables 3a and 3b.

Results showed that nitrogen management and weed management practices have significant influence on plant height of okra. Nitrogen management, n_1 recorded significantly taller plants with height of 43.96, 82.56 and 97.81 cm compared to n_2 (38.92, 75.85 and 90.96 cm) at 30, 60 DAS and at harvest, respectively.

Among the strategies for weed control, w_5 recorded significantly taller plants of 54.61, 92.77, 108.44 cm at 30, 60 DAS and at harvest, respectively which was on a par with w_3 at 60 DAS and at harvest (88.44 and 103.39 cm, respectively). The shorter plants of 25.11 and 66.72 cm were recorded at 30 and 60 DAS in w_2, while weedy check recorded the shorter plants (85.11cm) at harvest.

N x W interaction showed significant variation in plant height at 30 DAS. However, the interaction effect was not significant at 60 DAS and at harvest. The treatment combination n_1w_5 recorded significantly taller plants (59.33 cm) at 30 DAS. This was followed by n_1w_3 (55.33 cm) and n_1w_1 (51.77 cm). The shorter plants were recorded in n_2w_2 (24.33 cm) which was on a par with n_1w_2 (25.88 cm).

Table 3a. Effect of nitrogen management and weed management practices on plant height, cm

Treatments	30 DAS	60 DAS	At harvest
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	43.96	82.56	97.81
n_2 -100% N as urea as per KAU POP	38.92	75.85	90.96
SEm (±)	0.50	0.99	1.90
CD (0.05)	1.479	2.920	5.561
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	49.21	83.05	97.00
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	25.11	66.72	85.61
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	51.83	88.44	103.39
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	34.72	72.89	86.77
w_5 - HW at 15 and 30 DAS	54.61	92.77	108.44
w_6 - Weedy check	33.17	71.44	85.11
SEm (±)	0.87	1.72	3.28
CD (0.05)	2.561	5.058	9.631

(PE- pre- emergence, *fb*-followed by)

Table 3b. Interaction effect of nitrogen management and weed management practices on plant height, cm

Interactions	30 DAS	60 DAS	At harvest
N x W interaction			
n_1w_1	51.77	87.22	102.00
n_1w_2	25.88	67.44	80.89
n_1w_3	55.33	94.33	111.11
n_1w_4	37.00	74.33	88.33
n_1w_5	59.33	99.88	118.00
n_1w_6	34.44	72.33	86.55
n_2w_1	46.65	78.89	92.00
n_2w_2	24.33	66.00	90.33
n_2w_3	48.33	82.55	95.66
n_2w_4	32.44	71.44	85.22
n_2w_5	49.89	85.66	98.89
n_2w_6	31.89	70.55	83.66
SEm (±)	1.23	2.44	4.64
CD(0.05)	3.62	NS	NS

4.1.1.2 Number of Branches per Plant

Results on the effect of nitrogen management, weed management and their interaction on number of branches per plant at 30, 60 DAS and at harvest are presented in Tables 4a and 4b.

Results showed that nitrogen management and weed management practices had significant influence on number of branches per plant of okra. Nitrogen management, n_1 recorded plants with more number of branches (2.44) at 60 DAS than n_2 (2.05). However, n_1 had no significant influence on number of branches per plant at 30 DAS and at harvest.

Among the approaches to weed management, w_5 recorded significantly more number of branches per plant (1.50 and 2.72) at 30 and 60 DAS, respectively which was on a par with w_3 (1.33 and 2.61) and w_1(1.22 and 2.44). Least number of branches were produced in w_2 (0.33 and 1.78) and was on a par with w_4 (0.50 and 1.94). At harvest, w_5, w_3, and w_1 recorded significantly higher number of branches per plant (4.38, 4.22 and 3.94, respectively) and lower branching was noted in w_6,w_2 and w_4(2.83, 2.94 and 3.16, respectively). Least number of branches per plant was recorded in w_2 at 30 and 60 DAS (0.33 and 1.78, respectively) while weedy check recorded lowest (2.83) at harvest.

N x W interaction showed no significant variation in number of branches at 30, 60 DAS and at harvest.

Table 4a. Effect of nitrogen management and weed management practices on number of branches per plant

Treatments	30DAS	60 DAS	At harvest
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	1.05	2.44	3.74
n_2 -100% N as urea as per KAU POP	0.80	2.05	3.42
SEm (±)	0.14	0.12	0.137
CD (0.05)	NS	0.365	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	1.22	2.44	3.94
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	0.33	1.78	2.94
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	1.33	2.61	4.22
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	0.50	1.94	3.16
w_5 - HW at 15 and 30 DAS	1.50	2.72	4.38
w_6 - Weedy check	0.67	2.00	2.83
SEm (±)	0.25	0.22	0.24
CD (0.05)	0.731	0.633	0.696

Table 4b. Interaction effect of nitrogen management and weed management practices on number of branches

Interactions	30 DAS	60 DAS	At harvest
N x W interaction			
n_1w_1	1.44	2.66	4.33
n_1w_2	0.33	2.11	3.00
n_1w_3	1.55	2.77	4.44
n_1w_4	0.67	2.11	3.22
n_1w_5	1.67	2.88	4.55
n_1w_6	0.67	2.11	2.89
n_2w_1	1.00	2.22	3.55
n_2w_2	0.33	1.44	2.88
n_2w_3	1.11	2.44	3.99
n_2w_4	0.33	1.77	3.11
n_2w_5	1.33	2.55	4.22
n_2w_6	0.67	1.89	2.78
SEm (±)	0.35	0.30	0.33
CD(0.05)	NS	NS	NS

4.1.1.3 Number of Leaves per Plant

Results on the effect of nitrogen management, weed management and their interaction on number of leaves per plant at 30, 60 DAS and at harvest are presented in Tables 5a and 5b.

Results showed that nitrogen management had significant influence on number of leaves per plant of okra at 60 DAS and at harvest. Nitrogen management, n_1 produced plants with more number of leaves (15.23 and 9.37) compared to n_2 (13.39 and 8.15) at 60 DAS and at harvest, respectively. However, nitrogen management, had no significant influence on number of leaves per plant at 30 DAS.

Weed management practices had significant influence on number of leaves per plant at all the growth stages. Amongst the weed control tactics, w_5 (12.00, 17.72 and

11.16), w_3 (11.61, 16.89 and 10.83) and w_1 (11.11, 16.28 and 10.22) recorded significantly more number of leaves per plant at 30, 60 DAS and at harvest, respectively. The lowest number of leaves per plant was recorded in w_6 at all the stages (7.05, 9.17 and 5.44, respectively) which was on a par with w_2 (7.39) at 30 DAS.

N x W interaction showed significant variation in number of leaves only at 60 DAS. The treatment combination n_1w_5 has produced significantly more number of leaves per plant among the others (19.22) and it was found to be superior. This was followed by n_1w_3 (18.00) and n_1w_1 (17.44).

Table 5a. Effect of nitrogen management and weed management practices on number of leaves per plant

Treatments	30DAS	60 DAS	At harvest
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	10.14	15.23	9.37
n_2 -100% N as urea as per KAU POP	9.26	13.39	8.15
SEm (±)	0.31	0.12	0.26
CD (0.05)	NS	0.345	0.759
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	11.11	16.28	10.22
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	7.39	12.22	6.77
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	11.61	16.89	10.83
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	9.05	13.58	8.11
w_5 - HW at 15 and 30 DAS	12.00	17.72	11.16
w_6 - Weedy check	7.05	9.17	5.44
SEm (±)	0.54	0.20	0.45
CD (0.05)	1.595	0.597	1.314

Table 5b. Interaction effect of nitrogen management and weed management practices on number of leaves per plant

Interactions	30 DAS	60 DAS	At harvest
N x W interaction			
n_1w_1	11.77	17.44	11.33
n_1w_2	7.89	12.55	7.00
n_1w_3	12.11	18.00	11.66
n_1w_4	9.44	14.17	8.44
n_1w_5	12.44	19.22	11.89
n_1w_6	7.22	10.00	5.89
n_2w_1	10.44	15.11	9.11
n_2w_2	6.89	11.89	6.55
n_2w_3	11.11	15.78	10.00
n_2w_4	8.66	13.00	7.77
n_2w_5	11.55	16.22	10.44
n_2w_6	6.88	8.33	5.00
SEm (±)	0.77	0.29	0.63
CD(0.05)	NS	0.845	NS

4.1.1.4 Leaf Area Index

Results on the effect of nitrogen management, weed management and their interaction on leaf area index of okra is presented in Tables 6a and 6b.

Information regarding leaf area index at 20 and 40 days after sowing (DAS) revealed a substantial impact from nitrogen management practices. Nitrogen management, n_1 resulted in higher leaf area index at 20 DAS (0.42) and 40 DAS (0.99) compared to n_2 (0.37 and 0.83, respectively).

Leaf area index was also varied significantly with weed management practices at 20 and 40 DAS. Among the weed management practices, the highest leaf area index was indicated by the treatment w_5 at 20 DAS (0.53) and 40 DAS (1.17). It was followed by w_3 (0.48 and 1.06) at 20 DAS and 40 DAS, respectively.

NxW interaction effect was found to be significant in leaf area index of okra at 20 DAS and 40 DAS. At 20 DAS, the highest leaf area index was indicated by the combination n_1w_5 (0.59) which was significantly superior. It was followed by n_1w_3 (0.51). The least leaf area index was observed in n_2w_6 (0.26) which was on par with n_1w_6 (0.26) and n_2w_2 (0.28). Similarly at 40 DAS, the highest leaf area index was indicated by the combination n_1w_5 (1.37) which was significantly superior. This was followed by n_1w_3 (1.18). The leaf area index was observed lower in n_2w_6 (0.65) which was on par with n_1w_6 (0.70).

Table 6a. Effect of nitrogen management and weed management practices on leaf area index in okra

Treatments	Leaf Area Index	
	20 DAS	40 DAS
Nitrogen management (N)		
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	0.42	0.99
n_2 -100% N as urea as per KAU POP	0.37	0.83
SEm (±)	0.01	0.09
CD (0.05)	0.011	0.027
Weed management (W)		
w_1 -PE Pendimethalin at 1 kg ha^{-1}	0.45	0.986
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	0.29	0.755
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	0.48	1.061
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	0.36	0.831
w_5 - HW at 15 and 30 DAS	0.53	1.172
w_6 - Weedy check	0.26	0.674
SEm (±)	0.01	0.02
CD (0.05)	0.018	0.047

Table 6b. Interaction effect of nitrogen management and weed management practices on leaf area index in okra

Interactions	Leaf Area Index	
	20 DAS	40 DAS
NxW interaction		
n_1w_1	0.50	1.10
n_1w_2	0.31	0.78
n_1w_3	0.51	1.18
n_1w_4	0.37	0.86
n_1w_5	0.59	1.37
n_1w_6	0.26	0.70
n_2w_1	0.40	0.88
n_2w_2	0.28	0.74
n_2w_3	0.44	0.95
n_2w_4	0.35	0.81
n_2w_5	0.48	0.98
n_2w_6	0.26	0.65
SEm (±)	0.01	0.02
CD(0.05)	0.026	0.066

4.1.1.5 Dry Matter Production

Results on the effect of nitrogen management, weed management and their interaction on dry matter production at harvest are presented in Tables 7a and 7b.

Results showed that nitrogen management and weed management practices have significant influence on dry matter production of okra. Nitrogen management, n_1 produced plants with significantly more dry matter production of 104.53 g per plant at harvest.

Amidst the weed management tactics, w_5 was found to be significantly superior. It has recorded significantly higher dry matter production at harvest (115.76

g per plant). This was followed by w_3 (112.13 g per plant). The lowest dry matter production was recorded in w_6 at final harvest (80.93 g per plant).

N x W interaction showed significant variation in dry matter production at harvest. The treatment combination n_1w_5 has resulted in significantly more dry matter production (120.96 g per plant) and it was on par with the treatment combination n_1w_3 (117.16 g per plant) at harvest.

Table 7a. Effects of nitrogen management and weed management practices on dry matter production at final harvest, g per plant

Treatments	At harvest
Nitrogen management (N)	
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	104.53
n_2 -100% N as urea as per KAU POP	96.48
SEm (±)	0.58
CD (0.05)	1.695
Weed management (W)	
w_1 -PE Pendimethalin at 1 kg ha^{-1}	108.49
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	89.62
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	112.13
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	96.08
w_5 - HW at 15 and 30 DAS	115.76
w_6 - Weedy check	80.93
SEm (±)	1.00
CD (0.05)	2.936

Table 7b. Interaction effect of nitrogen management and weed management practices on dry matter production at final harvest, g per plant

Interactions	At harvest
NxW Interaction	
n_1w_1	115.49
n_1w_2	90.71
n_1w_3	117.16
n_1w_4	99.03
n_1w_5	120.96
n_1w_6	83.82
n_2w_1	101.49
n_2w_2	88.53
n_2w_3	107.11
n_2w_4	93.12
n_2w_5	110.57
n_2w_6	78.04
SEm (±)	1.42
CD(0.05)	4.152

4.1.2 Yield Parameters

4.1.2.1 Days to 50 per cent Flowering

Results on the effect of nitrogen management, weed management and their interaction on days to 50 per cent flowering are presented in Tables 8a and 8b. Days to 50 per cent flowering was not significantly influenced by nitrogen management and weed management practices and their interaction. Interaction effect was also found to be non-significant.

4.1.2.2 Number of Fruits per Plant

Results on the effect of nitrogen management, weed management and their interaction on number of fruits per plant are presented in Tables 8a and 8b.

Nitrogen management practices greatly influenced the number of fruits per plant. Nitrogen management, n_1 has produced significantly more number of fruits per plant with the highest of 26.51 compared to nitrogen management, n_2 (21.08).

Number of fruits per plant was also significantly impacted by weed management practices. The treatment w_5 resulted in the highest number of fruits per plant (32.43), and it was followed by w_3 (29.15). Lowest number of fruits per plant was recorded in w_6 (16.05), which was statistically on a par with w_2 which recorded 17.88.

N x W interaction showed significant variation in number of fruits per plant. The treatment combination n_1w_5 resulted in significantly more number of fruits per plant (37.30). This was followed by n_1w_3 (33.11). The least number of fruits were obtained in treatment combination n_2w_6 (16.00) which was statistically on par with n_2w_4 (18.50), n_2w_2 (16.33), and n_1w_6 (16.10).

4.1.2.3 Fruit Length

Results on the effect of nitrogen management, weed management and their interaction on fruit length are presented in Tables 8a and 8b.

Individual fruit length was remarkably influenced by nitrogen management practices and the highest fruit length was recorded in n_1 (15.13 cm) compared to n_2 (13.66 cm).

Data on weed management showed that w_5 recorded the highest fruit length (17.66 cm) and it was on a par with w_3 (16.38 cm). The fruit length was observed lower in weedy check (w_6) which recorded 10.96 cm and it was on par with w_2 which recorded 12.18 cm.

The NxW interaction effect was found to be non-significant.

4.1.2.4 Fruit Weight

Results on the effect of nitrogen management, weed management and their interaction on fruit weight are presented in Tables 8a and 8b.

Nitrogen management had significantly altered the individual fruit weight of okra. Nitrogen management, n_1 resulted in the highest fruit weight (18.31 g) compared to nitrogen management, n_2 (16.08 g).

Weed management practices also had a significant impact on fruit weight. The highest fruit weight was recorded in w_5 (22.34 g) and it was statistically on par with w_3 (20.82). Lowest fruit weight was recorded in weedy check (11.57 g) which was on par with w_2 (12.73 g).

The NxW interaction effect was found to be not significant.

Table 8a. Effect of nitrogen management and weed management practices on yield attributes of okra.

Treatments	Yield attributes			
	Days to 50% flowering	Number of fruits per plant	Fruit length (cm)	Fruit weight (g)
Nitrogen management (N)				
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	38.78	26.51	15.13	18.31
n_2 -100% N as urea as per KAU POP	38.89	21.08	13.66	16.08
SEm (±)	1.15	0.48	0.29	0.40
CD (0.05)	NS	1.401	0.854	1.161
Weed management (W)				
w_1 -PE Pendimethalin at 1 kg ha^{-1}	37.67	27.16	15.67	19.50
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	41.33	17.88	12.18	12.73
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	37.33	29.15	16.38	20.82
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	41.00	20.08	13.52	16.20
w_5 - HW at 15 and 30 DAS	36.83	32.43	17.66	22.34
w_6 - Weedy check	38.83	16.05	10.96	11.57
SEm (±)	2.00	0.83	0.51	0.69
CD (0.05)	NS	2.427	1.480	2.011

Table 8b. Interaction effect of nitrogen management and weed management practices on yield attributes of okra

Interactions	Days to 50% flowering	Number of fruits per plant	Fruit length (cm)	Fruit weight (g)
N x W interaction				
n_1w_1	37.33	31.44	16.67	21.09
n_1w_2	41.00	19.43	12.60	13.08
n_1w_3	37.33	33.11	17.27	22.62
n_1w_4	40.67	21.67	14.05	16.83
n_1w_5	36.33	37.30	19.03	24.43
n_1w_6	40.00	16.10	11.17	11.80
n_2w_1	38.00	22.86	14.67	17.90
n_2w_2	41.67	16.33	11.77	12.37
n_2w_3	37.33	25.19	15.50	19.02
n_2w_4	41.33	18.50	12.98	15.57
n_2w_5	37.33	27.57	16.28	20.26
n_2w_6	37.67	16.00	10.75	11.34
SEm (±)	2.82	1.17	0.71	0.97
CD(0.05)	NS	3.432	NS	NS

4.1.2.5 Fruit Yield per Plant

Results on the effect of nitrogen management, weed management and their interaction on fruit weight are presented in Tables 9a and 9b.

Perusal of data on nitrogen management revealed that n_1 resulted in the highest fruit yield per plant (614.28 g) compared to n_2 (426.95 g)

Weed management had significant impact on fruit yield per plant. w_5 was found to be superior to all other treatments. The highest fruit yield per plant was recorded in w_5 (856.09 g). It was followed by w_3 (721.62 g). Least fruit yield per plant was recorded in the treatment w_2 (251.73 g).

Interaction effect was also found to be significant. NxW interaction showed significant variation in fruit yield per plant. The treatment combination n_1w_5 recorded significantly more yield per plant (1070.22 g) and it was followed by n_1w_3 (901.34 g). Least was recorded in n_2w_2 (248.64 g) which was statistically on par with n_1w_2 (254.81 g) and n_2w_6 (300.83 g)

4.1.2.6 Haulm Yield per Plant

Results on the effect of nitrogen management, weed management and their interaction fruit weight are shown in Tables 9a and 9b.

Nitrogen management had pronounced impact on dry haulm yield per plant. The highest haulm yield per plant (50.07 g) was recorded in n_1 whereas a haulm yield per plant of 43.91 g was produced in n_2.

Among the weed management practices, the treatment w_5 resulted in the highest haulm yield per plant (56.13 g), and it was followed by w_3 (53.15 g). Lowest haulm yield per plant was observed in w_6 (weedy check) (39.54 g).

The interaction effect was also found to be significant in haulm yield per plant. The treatment combination n_1w_5 has produced significantly more haulm yield per plant (61.9 g) which was statistically comparable with the combination n_1w_3 (58.80 g). Among the combinations, least haulm yield per plant was produced by n_2w_6 (39.27 g) which was on par with n_1w_6 (39.81g), n_2w_2 (39.85 g) and n_1w_2 (41.13 g).

Table 9a. Effect of nitrogen management and weed management practices on yield per plant, g

Treatments	Fruit yield per plant	Haulm yield per plant
Nitrogen management (N)		
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	614.28	50.07
n_2 -100% N as urea as per KAU POP	426.95	43.91
SEm (±)	9.20	0.52
CD (0.05)	46.737	1.516
Weed management (W)		
w_1 -PE Pendimethalin at 1 kg ha^{-1}	635.93	48.68
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	251.73	40.49
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	721.62	53.15
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	348.42	43.92
w_5 - HW at 15 and 30 DAS	856.09	56.13
w_6 - Weedy check	309.90	39.54
SEm (±)	15.94	0.90
CD (0.05)	46.737	2.626

Table 9b. Interaction effect of nitrogen management and weed management practices on yield per plant, g

Interactions	Fruit yield per plant	Haulm yield per plant
N xW interaction		
n_1w_1	769.88	53.17
n_1w_2	254.81	41.13
n_1w_3	901.34	58.80
n_1w_4	370.47	45.59
n_1w_5	1070.22	61.90
n_1w_6	318.97	39.81
n_2w_1	501.98	44.20
n_2w_2	248.64	39.85
n_2w_3	541.90	47.50
n_2w_4	326.38	42.25
n_2w_5	641.97	50.37
n_2w_6	300.83	39.27
SEm (±)	22.54	1.27
CD(0.05)	66.096	3.714

4.1.2.7 Fruit Yield per Hectare

Results on the effect of nitrogen management, weed management and their interaction on fruit yield per hectare are shown in Tables 10a and 10b.

Data on fruit yield per hectare showed that it was significantly impacted by nitrogen management practices. Nitrogen management, n_1 resulted in the highest fruit yield per hectare (2250 kg ha^{-1}) compared to n_2 (1563 kg ha^{-1}).

Among the weed management practices, the treatment w_5 was found to be significantly superior to other treatments and it has produced the highest fruit yield per hectare of 3135 $kgha^{-1}$. This was followed by w_3 (2643 $kgha^{-1}$). Least fruit yield per hectare was recorded in w_2 (922 kg ha^{-1}).

NxW interaction was also found significant in fruit yield per hectare. Among the treatment combinations, n_1w_5 was found to be significantly superior and it has resulted in the fruit yield of 3920 kg ha^{-1}. It was followed by n_1w_3 (3301 kg ha^{-1}). The least fruit yield per hectare was recorded in the treatment combination n_2w_2 (910 kg ha^{-1}) which is on a par with n_1w_2 (933 kg ha^{-1}) and n_2w_6 (1101 kg ha^{-1}).

4.1.2.8 Haulm Yield per Hectare

Results on the effect of nitrogen management, weed management and their interaction on haulm yield per hectare are shown in Tables 10a and 10b.

Data on fruit yield per hectare showed that it was significantly altered by nitrogen management practices. Nitrogen management, n_1 resulted in the highest haulm yield (1833 kg ha^{-1}) compared to n_2 (1608 kg ha^{-1}).

Among the weed management practices, the treatment w_5 was found to be significantly superior to other treatments and it has produced the highest haulm yield of 2054 kg. The treatment w_5 was followed by w_3, w_1, and w_4. Least haulm yield per hectare was recorded in w_6 (1448 kg ha^{-1}) and it was statistically on par with w_2 (1483 kg ha^{-1}).

NxW interaction was also found significant in haulm yield per hectare. Among the treatment combinations, n_1w_5 resulted in highest haulm yield of 2263 kg ha^{-1} and it was statistically comparable with n_1w_3 (2153 kg ha^{-1}). Haulm yield per hectare was recorded in the treatment combination n_2w_6 (1438 kg ha^{-1}) was lower which is on par with n_1w_6 (1458 kg ha^{-1}), n_2w_2 (1459 kg ha^{-1}), n_1w_2 (1506 kg ha^{-1}), and n_2w_4 (1547 kg ha^{-1}).

Table 10a. Effect of nitrogen management and weed management practices on yield per hectare in okra, kg ha^{-1}

Treatments	Fruit yield per hectare	Haulm yield per hectare
Nitrogen management (N)		
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	2250	1833
n_2 -100% N as urea as per KAU POP	1563	1608
SEm (±)	33.70	18.91
CD (0.05)	98.841	55.459
Weed management (W)		
w_1 -PE Pendimethalin at 1 kg ha^{-1}	2329	1783
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	922	1483
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	2643	1946
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	1276	1608
w_5 - HW at 15 and 30 DAS	3135	2054
w_6 - Weedy check	1135	1448
SEm (±)	58.37	32.75
CD (0.05)	171.198	96.057

Table 10b. Interaction effect of nitrogen management and weed management practices on yield per hectare in okra, kg ha^{-1}

Interactions	Fruit yield per hectare	Haulm yield per hectare
NxW interaction		
n_1w_1	2820	1947
n_1w_2	933	1506
n_1w_3	3301	2153
n_1w_4	1357	1670
n_1w_5	3920	2263
n_1w_6	1168	1458
n_2w_1	1838	1619
n_2w_2	910	1459
n_2w_3	1984	1739
n_2w_4	1195	1547
n_2w_5	2351	1844
n_2w_6	1101	1438
SEm (±)	82.55	46.32
CD(0.05)	242.111	135.846

4.1.2.9 Harvest Index

The main and interaction effects of nitrogen and weed management practices on harvest index of okra is presented in Tables 11a and 11b.

Data on harvest index showed that it was significantly impacted by nitrogen management practices. Nitrogen management, n_1 resulted in higher harvest index (0.52) compared to n_2 (0.49).

Harvest index was also significantly modified by weed management practices. Among the weed management practices, the highest harvest index recorded by w_5 (0.60) which was on a par with w_3 (0.58) and w_1 (0.56). The lowermost harvest index was recorded by w_2 (0.38).

N x W interaction effect was found to be significant in harvest index of okra. The highest harvest index was indicated by the combination n_1w_5 (0.65) which was on par with n_1w_3 (0.62) and n_1w_1 (0.60).

4.1.2.10 Weed Index

The degree of reduction in yield by weeds were assessed considering hand weeding twice as the control treatment, analysed statistically and represented in Tables 11a and 11b.

Data on weed index revealed that it was significantly affected by nitrogen management practices. Nitrogen management, n_2 resulted in higher yield reduction with a weed index of 60.33 per cent compared to n_1 (42.59 %).

Weed management practices had significant influence on weed index. Among the weed management practices, weed index observed was least in w_5 (21.15 %) and was superior. The maximum yield reduction was recorded in w_2 with a weed index of 77.22 per cent. This was on par with w_6 (70.12 %) and followed by w_4 (66.63 %).

N x W interaction effect was also found to be significant. The minimum yield reduction was observed in n_1w_5 (0.00 %). The highest weed index was indicated by n_1w_2 (78.15 %) and it was statistically comparable with n_2w_2 (76.28 %), n_2w_6 (70.36 %), n_1w_6 (69.88%) and n_2w_4 (68.98 %) respectively.

Table 11a. Effect of nitrogen management and weed management practices on harvest index and weed index in okra

Treatments	Harvest index	Weed index (%)
Nitrogen management (N)		
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	0.52	42.59 (5.97)
n_2 -100% N as urea as per KAU POP	0.49	60.33 (7.79)
SEm (±)	0.01	0.08
CD (0.05)	0.021	0.249
Weed management (W)		
w_1 -PE Pendimethalin at 1 kg ha^{-1}	0.56	41.43 (6.42)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	0.38	77.22 (8.84)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	0.58	32.22 (5.57)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	0.45	66.63 (8.22)
w_5 - HW at 15 and 30 DAS	0.60	21.15 (3.78)
w_6 - Weedy check	0.45	70.12 (8.43)
SEm (±)	0.01	0.14
CD (0.05)	0.037	0.431

(The data were subjected to square root transformation and transformed values are given in parenthesis)

Table 11b. Interaction effect of nitrogen management and weed management practices on harvest index and weed index in okra

Interactions	Harvest index	Weed index (%)
NxW interaction		
n_1w_1	0.60	27.70 (5.35)
n_1w_2	0.38	78.15 (8.90)
n_1w_3	0.62	15.54 (4.07)
n_1w_4	0.46	64.27 (8.08)
n_1w_5	0.65	0.00 (1.00)
n_1w_6	0.46	69.88 (8.42)
n_2w_1	0.53	55.16 (7.49)
n_2w_2	0.39	76.28 (8.79)
n_2w_3	0.55	48.91 (7.06)
n_2w_4	0.45	68.98 (8.36)
n_2w_5	0.55	42.30 (6.56)
n_2w_6	0.45	70.36 (8.45)
SEm (±)	0.02	0.20
CD(0.05)	0.052	0.610

(The data were subjected to square root transformation and transformed values are given in parenthesis)

4.2 OBSERVATIONS ON WEED

4.2.1 Weed Flora

Results of predominant species of weeds observed in the experimental field were detailed in the Table 12.

Predominant weed flora of the experiment field was grasses. However, more diversity was observed in broad leaf weeds (BLW). *Setaria barbata* (Lam.) Kunth, *Digitaria sanguinalis* (L.) Scop, *Echinochloa colona* L., *Cynodon dactylon* L. were the grass species present in the experimental field. Many BLW species were found in the experimental field. Among those, the predominant ones were *Trianthema portulacastrum* L., *Cleome rutidosperma* L., *Alternanthera sessilis* L., *Synedrella nodiflora* (L.) Gaertn, *Phyllanthus niruri* L., *Euphorbia geniculata* L., *Boerhaavia diffusa* L., and *Tridax procumbens* L. Diversity of sedges was low and *Cyperus rotundus* L. was the only sedge observed in the experimental field.

Table 12. Predominant weed flora of experimental field

Scientific name	Common name	Malayalam name	Family
		Grasses	
Panicum maximum L.	Guinea grass	*Kuthira pullu*	Poaceae
Setaria barbata (Lam.) Kunth	East Indian bristle grass		Poaceae
Digitaria sanguinalis (L.) Scop.	Large Crab grass		Poaceae
Echinochloa colona	Barnyard grass	*Kavada*	Poaceae
Cynodon dactylon L.	Bermuda grass	*Karuka pullu*	Poaceae
		Broad leaved weeds	
Synedrella nodiflora (L.) Gaertn.	Cindrella weed	*Venapacha*	Asteraceae
Phyllanthus niruri L.	Stone breaker weed	*Keezharnelli*	Euphorbiaceae
Boerhaavia diffusa L.	Spreading hogweed	*Thazhuthama*	Nyctaginaceae
Mimosa pudica L.	Touch me not	*Thottavaadi*	Fabaceae
Tridax procumbens L.	Coat button	*Thalavetti*	Asteraceae
Trianthema portulacastrum L.	Desert horse-purslane		Aizoaceae
Commelina benghalensis L.	Benghal day flower	*Vaazhapadathi*	Commelinaceae
Commelina jacobi L.	Creeping day flower	*Vaazhapadathi*	Commelinaceae
Alternanthera sessilis L.	Sessile joyweed	*Kozhuppacheera*	Amaranthaceae
Cleome rutidosperma L.	Spider flower	*Kattukaduku*	Cleomaceae
Euphorbia hirta L.	Asthma herb	*Tharavu*	Euphorbiaceae

Euphorbia geniculata L.	Milk-weed		Euphorbiaceae
Richardia scabra L.	Rough Mexican clover		Rubiaceae
Sedges			
Cyperus rotundus L.	Purple nut sedge	*Muthanga*	Cyperaceae

4.2.2 Weed Density

Results of the total density of grasses, sedges and broad leaf weeds at 15, 30 and 45 DAS are presented in Table 13 a, 13b, 14a, 14b, 15a and 15b.

Density of Grasses

Data on total density of grasses showed that it was significantly influenced by nitrogen management practices only at 45 DAS (Tables 13a and 13b). Nitrogen management, n_1 resulted in lower density of grasses (8.89 no. m^{-2}) compared to n_2 (9.11 no. m^{-2}) at 45 DAS. However, nitrogen management had no significant influence on density of grasses at 15 and 30 DAS.

Weed management practices also had significant influence on density of grasses at 15 and 45 DAS. Among the weed management practices, the treatments w_4 (2.50 no. m^{-2}), w_2 (2.67 no. m^{-2}), w_3 (5.50 no. m^{-2}) and w_1 (6.00 no. m^{-2}) produced the least density of grasses at 15 DAS. However, at 45 DAS, w_4 has produced lower density of grasses (6.67 no. m^{-2}) followed by w_3 (6.67 no. m^{-2}) and w_1 (8.00 no. m^{-2}).

NxW interaction was found to be significant in density of grasses at 15 DAS. Least density of grasses was produced by n_2w_2 (1.33 no. m^{-2}) which was on par with n_2w_4 (2.33 no. m^{-2}), n_1w_4 (2.67 no. m^{-2}), n_1w_1 (2.67 no. m^{-2}), n_1w_2 (4.00 no. m^{-2}), and n_1w_3 (4.00 no. m^{-2}).

Table 13a. Effect of nitrogen management and weed management practices on density of grasses at 15, 30 and 45 DAS, no. m^{-2}

Treatments	Density of grasses		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	6.67 (2.52)	7.56 (2.53)	8.89 (1.92)
n_2 -100% N as urea as per KAU POP	7.78 (2.78)	6.67 (2.46)	9.11 (2.79)
SEm (±)	0.17	0.32	0.23
CD (0.05)	NS	NS	0.660
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha-1	6.00 (2.51)	4.00 (1.98)	8.00 (2.71)
w_2 -PE Oxyfluorfen at 0.15 kg ha-1	2.67 (1.75)	7.33 (2.41)	15.33 (3.02)
w_3 - PE Pendimethalin at 1 kg ha-1*fb* HW at 30 DAS	5.50 (2.53)	10.00 (2.96)	6.67 (1.54)
w_4 - PE Oxyfluorfen at 0.15 kg ha-1 *fb* HW at 30 DAS	2.50 (1.74)	4.67 (2.21)	6.67 (1.00)
w_5 - HW at 15 and 30 DAS	12.67 (3.59)	4.00 (1.98)	5.33 (3.09)
w_6 - Weedy check	14.00 (3.79)	12.67 (3.46)	12.00 (2.78)
SEm (±)	0.29	0.55	0.39
CD (0.05)	0.847	NS	1.143

(The data were subjected to square root transformation and transformed values are given in parenthesis)

Table 13b. Interaction effect of nitrogen management and weed management practices on density of grasses at 15, 30 and 45 DAS, no. m^{-2}

Interactions	Density of grasses		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	2.67 (1.82)	6.67 (2.54)	8.00 (2.71)
n_1w_2	4.00 (2.08)	13.33 (3.41)	22.67 (2.91)
n_1w_3	4.00 (2.24)	10.67 (3.00)	6.67 (1.00)
n_1w_4	2.67 (1.67)	5.33 (2.33)	5.33 (1.00)
n_1w_5	17.33 (4.17)	0.00 (1.00)	5.33 (2.08)
n_1w_6	9.33 (3.15)	9.33 (2.91)	5.33 (1.83)
n_2w_1	9.33 (3.20)	1.33 (1.41)	8.00 (2.71)
n_2w_2	1.33 (1.41)	1.33 (1.41)	8.00 (3.12)
n_2w_3	7.00 (2.83)	9.33 (2.91)	6.67 (2.08)
n_2w_4	2.33 (1.82)	4.00 (2.08)	8.00 (1.00)
n_2w_5	8.00 (3.00)	8.00 (2.95)	5.33 (4.10)
n_2w_6	18.67 (4.43)	16.00 (4.00)	18.67 (3.73)
SEm (±)	0.41	0.77	0.55
CD(0.05)	1.198	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis)

Density of Sedges

Perusal of data on total density of sedges indicated that it was not significantly modified by nitrogen management practices and weed management practices at all the growth stages (Tables 14a and 14b).

NxW interaction was found to be significant only at 30 DAS in density of sedges. Density of sedges recorded was lower in the treatment combination n_2w_6 (0.00 no. m^{-2}) and n_1w_1 (0.00 no. m^{-2}), which were at par with n_1w_4 (2.67 no. m^{-2}), n_2w_3

(4.00 no. m^{-2}), n_2w_5 (5.33 no. m^{-2}), n_1w_6 (6.67 no. m^{-2}), n_1w_2 (6.67 no. m^{-2}), and n_1w_3 (9.33 no. m^{-2}).

Table 14a. Effect of nitrogen management and weed management practices on density of sedges at 15, 30 and 45 DAS, no. m^{-2}

Treatments	Density of sedges		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	4.00 (1.94)	6.44 (2.39)	15.33 (3.54)
n_2 -100% N as urea as per KAU POP	6.89 (2.41)	11.56 (3.03)	12.89 (3.09)
SEm (±)	0.26	0.32	0.44
CD (0.05)	NS	NS	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha-1	6.00 (2.24)	6.67 (2.17)	18.00 (3.85)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	4.00 (2.03)	18.67 (4.06)	11.33 (2.77)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	3.33 (1.73)	6.67 (2.31)	14.67 (3.45)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	6.00 (2.18)	9.33 (2.85)	22.00 (4.67)
w_5 - HW at 15 and 30 DAS	10.67 (3.13)	9.33 (3.08)	1.33 (1.41)
w_6 - Weedy check	2.67 (1.75)	3.33 (1.77)	17.33 (3.72)
SEm (±)	0.46	0.55	0.76
CD (0.05)	NS	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis)

Table 14b. Interaction effect of nitrogen management and weed management practices on density of sedges at 15, 30 and 45 DAS, no. m^{-2}

Interactions	Density of sedges		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	1.33 (1.41)	0.00 (1.00)	10.67 (3.27)
n_1w_2	4.00 (1.83)	6.67 (2.70)	21.33 (4.13)
n_1w_3	5.33 (2.04)	9.33 (2.75)	18.67 (3.84)
n_1w_4	2.67 (1.83)	2.67 (1.67)	13.33 (3.75)
n_1w_5	9.33 (3.12)	13.33 (3.67)	0.00 (1.00)
n_1w_6	1.33 (1.41)	6.67 (2.54)	28.00 (5.25)
n_2w_1	10.67 (3.06)	13.33 (3.33)	25.33 (4.43)
n_2w_2	4.00 (2.24)	30.67 (5.43)	1.33 (1.41)
n_2w_3	1.33 (.41)	4.00 (1.87)	10.67 (3.06)
n_2w_4	9.33 (2.54)	16.00 (4.04)	30.67 (5.60)
n_2w_5	12.00 (3.13)	5.33 (2.49)	2.67 (1.83)
n_2w_6	4.00 (2.08)	0.00 (1.00)	6.67 (2.19)
SEm (±)	0.65	0.77	1.075
CD(0.05)	NS	2.266	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis)

Density of BLW

Data on total density of BLW showed that it was not significantly changed by nitrogen management practices at all the growth stages (Tables 15a and 15b).

Weed management practices had significant influence on density of BLW at 15 DAS. Within the weed management practices, the treatment w_4 has produced lowest density of BLW at 15 DAS (1.33 no. m^{-2}) and it was statistically on a par with w_2 (2.18 no. m^{-2}).

NxW interaction was found to be not significant with respect to density of BLW.

Table 15a. Effect of nitrogen management and weed management practices on weed density of BLW at 15, 30 and 45 DAS, no. m^{-2}

Treatments	Density of BLW		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	12.22 (3.25)	13.56 (3.54)	7.78 (2.76)
n_2 -100% N as urea as per KAU POP	7.56 (2.71)	10.22 (3.25)	6.22 (2.26)
SEm (±)	0.21	0.28	0.30
CD (0.05)	NS	NS	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	6.67 (2.72)	12.67 (3.68)	8.00 (2.87)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	6.00 (2.18)	9.33 (3.06)	9.33 (3.06)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	13.33 (3.60)	11.33 (3.25)	8.67 (2.49)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	2.00 (1.33)	8.00 (2.83)	2.00 (1.54)
w_5 - HW at 15 and 30 DAS	16.67 (4.14)	12.67 (3.47)	6.67 (2.39)
w_6 - Weedy check	14.67 (3.90)	17.33 (4.09)	7.33 (2.70)
SEm (±)	0.37	0.49	0.52
CD (0.05)	1.089	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis)

Table 15b. Interaction effect of nitrogen management and weed management practices on density of BLW at 15, 30 and 45 DAS, no. m^{-2}

Interactions	Density of BLW		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	9.33 (3.20)	13.33 (3.78)	10.67 (3.41)
n_1w_2	8.00 (2.28)	13.33 (3.62)	9.33 (2.91)
n_1w_3	18.67 (4.23)	12.00 (3.13)	5.33 (2.28)
n_1w_4	0.00 (1.00)	8.00 (2.71)	4.00 (2.08)
n_1w_5	18.67 (4.37)	10.67 (3.16)	13.33 (3.78)
n_1w_6	18.67 (4.40)	24.00 (4.86)	4.00 (2.08)
n_2w_1	4.00 (2.24)	12.00 (3.58)	5.33 (2.33)
n_2w_2	4.00 (2.08)	5.33 (2.50)	9.33 (3.20)
n_2w_3	8.00 (2.95)	10.67 (3.37)	12.00 (2.69)
n_2w_4	4.00 (1.67)	8.00 (2.95)	0.00 (1.00)
n_2w_5	14.67 (3.90)	14.67 (3.79)	0.00 (1.00)
n_2w_6	10.67 (3.41)	10.67 (3.32)	10.67 (3.32)
SEm (±)	0.53	0.69	0.73
CD(0.05)	NS	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis)

4.2.3 Weed Dry Weight

Results of the total dry weight of weeds at 15, 30 and 45 DAS are presented in Tables 16a and 16b.

Data on total dry weight of weeds indicated that it was significantly impacted by nitrogen management practices at 30 DAS and 45 DAS. Nitrogen management, n_1 resulted in lowest dry weight of weeds (8.61 g m^{-2} and 8.77 g m^{-2}) compared to n_2 (14.30 g m^{-2} and 15.43 g m^{-2}) at 30 DAS and 45 DAS, respectively.

Weed management practices also had significant influence on weed dry weight at all the growth stages. Amongst the weed control practices, w_2 recorded the least dry weight of weeds at 15 DAS (2.07 g m^{-2}) and it was significantly superior. However, at 30 DAS, the treatment w_5 had lowest dry weight of weeds (1.51 g m^{-2}) and it was significantly superior. At 45 DAS, the treatment w_4 resulted in lower dry weight of weeds (2.92 g m^{-2}) and it was statistically on par with w_3 (3.57 g m^{-2}) and w_5(5.22 g m^{-2}).

The effect of NxW interaction was found to be significant with respect to total dry weight of weeds at 15 and 30 DAS. At 15 DAS, $n_2w_2$had registered lowest weed dry weight (1.63 g m^{-2}) and it was on a par with n_2w_1 (1.79 g m^{-2}), n_1w_2 (2.50 g m^{-2}), and n_1w_4 (2.69 g m^{-2}). Similarly at 30 DAS, $n_1w_5$had registered lowest weed dry weight (1.39 g m^{-2}) and it was on a par with n_2w_5 (1.64 g m^{-2}), and n_1w_4 (2.95 g m^{-2})

Table 16a. Effect of nitrogen management and weed management practices on weed dry weight at 15, 30 and 45 DAS, g.

Treatments	Dry weight of weeds		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	13.83	8.61	8.77
n_2 -100% N as urea as per KAU POP	12.63	14.30	15.43
SEm (±)	0.90	0.83	0.82
CD (0.05)	NS	2.428	2.405
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	9.05	15.75	17.59
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	2.07	11.85	26.54
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	16.00	14.42	3.57
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	9.42	6.55	2.92
w_5 - HW at 15 and 30 DAS	21.81	1.51	5.22
w_6 - Weedy check	21.04	18.65	16.78
SEm (±)	1.57	1.43	1.42
CD (0.05)	4.591	4.206	4.165

Table 16b. Interaction effect of nitrogen management and weed management practices on weed dry weight at 15, 30 and 45 DAS, g.

Interactions	Dry weight of weeds		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	16.30	23.06	10.59
n_1w_2	2.50	13.47	17.43
n_1w_3	17.72	16.74	4.57
n_1w_4	2.69	2.95	2.43
n_1w_5	21.91	1.39	6.32
n_1w_6	21.88	28.19	11.30
n_2w_1	1.79	8.44	24.57
n_2w_2	1.63	10.22	35.65
n_2w_3	14.28	12.11	2.57
n_2w_4	16.14	10.14	3.41
n_2w_5	21.72	1.64	4.13
n_2w_6	20.21	9.12	2.01
SEm (±)	2.21	2.03	5.89
CD(0.05)	6.49	5.948	NS

4.2.4 Weed Control Efficiency

The influence of nitrogen and weed management practices on weed control efficiency in okra is presented in Tables 17a and 17b.

Data revealed significant influence of nitrogen management practices on weed control efficiency at 30 DAS and 45 DAS, with n_1 resulting in higher weed control efficiency (60.92 and 63.76 %, respectively) than n_2 (54.95 % and 49.42, respectively).

Weed control efficiency was significantly modified by weed management practices. Amid the weed management practices, the highest weed control efficiency was recorded by w_2 (94.08 %) at 15 DAS. A lower weed control efficiency was noticed in w_6 (10.79 %) which was on a par with w_5 (11.91 %). At 30 DAS, the highest WCE was observed in the treatment w_5 (94.82 %) which was significantly superior. The least WCE was indicated by w_6 (5.05 %). However, at 45 DAS, the highest weed control efficiency was produced by w_3 (89.35 %) which was on a par with w_5 (88.77 %). WCE was the least in weedy check (7.98 %).

N x W interaction effect was found to be significant in weed control efficiency at 15, 30 and 45 DAS. At 15 DAS, the highest weed control efficiency was recorded by n_2w_2 (98.96 %) which was on a par with n_2w_1 (97.96%), n_1w_4 (93.95 %) and n_1w_2 (89.21 %). And n_2w_6 recorded least WCE during all stages (0.00 %).

Similarly at 30 DAS, the highest weed control efficiency was recorded in combination n_1w_5 (95.22 %) which was on par with n_2w_5 (94.43 %), n_1w_4 (89.63 %) and n_2w_1 (70.97 %). The lower most was recorded in n_2w_6 and was on par with n_1w_6. At 45 DAS, the highest weed control efficiency was recorded in the combination n_1w_4 (92.80 %) which was on par with n_2w_3 (92.14 %), n_1w_5 (90.12 %), n_2w_5 (87.41 %) and n_1w_3 (86.55 %).

Table 17a. Effect of nitrogen management and weed management practices on weed control efficiency in okra at 15, 30 and 45 DAS, per cent.

Treatments	Weed control efficiency		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	48.00 (6.59)	60.92 (7.56)	63.76 (7.61)
n_2 -100% N as urea as per KAU POP	52.54 (6.45)	54.95 (6.92)	49.42 (6.33)
SEm (±)	2.75	1.69	1.49
CD (0.05)	NS	4.944	4.358
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	67.50 (8.06)	67.47 (8.26)	57.43 (7.49)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	94.08 (9.74)	53.93 (7.38)	14.52 (3.84)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	37.75 (6.09)	59.75 (7.79)	89.35 (9.50)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	79.58 (8.86)	66.60 (8.08)	81.52 (9.05)
w_5 - HW at 15 and 30 DAS	11.91 (3.52)	94.82 (9.79)	88.77 (9.47)
w_6 - Weedy check	10.79 (2.85)	5.05 (2.15)	7.98 (2.46)
SEm (±)	4.75	2.92	2.57
CD (0.05)	13.943	8.563	7.548

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Table 17b. Interaction effect of nitrogen management and weed management practices on weed control efficiency in okra at 15, 30 and 45 DAS, per cent.

Interactions	Weed control efficiency		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	37.04 (6.17)	63.97 (8.06)	80.30 (9.02)
n_1w_2	89.21 (9.50)	48.37 (7.01)	16.85 (4.12)
n_1w_3	34.00 (5.89)	58.22 (7.69)	86.55 (9.36)
n_1w_4	93.95 (9.74)	89.63 (9.52)	92.80 (9.68)
n_1w_5	12.24 (3.56)	95.22 (9.81)	90.12 (9.55)
n_1w_6	21.57 (4.69)	10.10 (3.29)	15.96 (3.92)
n_2w_1	97.96 (9.95)	70.97 (8.47)	34.55 (5.96)
n_2w_2	98.96 (9.99)	59.48 (7.75)	12.19 (3.56)
n_2w_3	41.51 (6.29)	61.28 (7.89)	92.14 (9.65)
n_2w_4	65.22 (7.98)	43.56 (6.64)	70.24 (8.41)
n_2w_5	11.58 (3.48)	94.43 (9.77)	87.41 (9.40)
n_2w_6	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
SEm (±)	6.72	4.13	3.64
CD(0.05)	19.72	12.110	10.674

(The data were subjected to square root transformation and transformed values are given in parenthesis).

4.2.5 Relative Weed Density

Results on the effect of nitrogen and weed management practices on relative weed density of grasses, sedges and broad leaf weeds are detailed in Tables 18a, 18b, 19a, 19b, 20a, and 20b.

Relative Density of Grasses

Data on relative density of grasses has revealed that it was significantly affected by nitrogen management practices only at 45 DAS (Tables 18a and 18b).

Nitrogen management, n_1 resulted in lower relative density of grasses at 45 DAS (16.05 %) compared to n_2 (39.21 %).

Weed management practices had significant influence on relative density of grasses only at 45 DAS. Among the weed control practices, lower relative density of grasses was produced by w_4 (0.00 %) which was on par with w_3 (11.25 %). The highest relative density of grasses was noticed in w_5 (65.52 %).

N x W interaction effect was found to be significant in relative density of grasses at 30 DAS. Density of grasses recorded was lower in n_2w_2 (0.00 %) and n_1w_5 which were on a par with n_2w_1 (7.50 %), n_1w_3 (12.50 %), n_2w_4 (14.29 %), n_1w_4 (25.00 %), n_1w_6 (35.00 %) and n_2w_5 (35.71 %). Higher relative density grass weeds were observed in n_2w_3 (58.33 %) and was on a par with n_1w_2 (54 %).

Table 18a. Effect of nitrogen management and weed management practices on relative weed density of grasses at 15, 30 and 45 DAS, per cent.

Treatments	Relative density of grasses		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	32.01 (4.56)	29.42 (4.66)	16.05 (3.30)
n_2 -100% N as urea as per KAU POP	33.20 (5.36)	25.56 (4.44)	39.21 (5.48)
SEm (±)	0.97	0.67	0.54
CD (0.05)	NS	NS	1.665
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	28.33 (4.89)	28.75 (4.80)	30.80 (5.07)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	10.71 (2.41)	27.00 (3.86)	32.50 (5.04)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	42.86 (5.92)	35.42 (5.37)	11.25 (2.89)
w_4 - PE Oxyfluorfen at 0.15 kg ha-1 *fb* HW at 30 DAS	43.75 (4.85)	19.64 (3.65)	0.00 (1.00)
w_5 - HW at 15 and 30 DAS	28.51 (5.17)	17.86 (3.52)	65.52 (7.87)
w_6 - Weedy check	41.46 (6.51)	36.25 (6.08)	25.71 (4.47)
SEm (±)	1.67	1.16	0.93
CD (0.05)	NS	NS	2.884

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Table 18b. Interaction effect of nitrogen management and weed management practices on relative density of grasses at 15, 30 and 45 DAS, per cent.

Interactions	Relative density of grasses		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	15.00 (3.28)	50.00 (7.11)	40.91 (6.39)
n_1w_2	0.00 (1.00)	54.00 (6.73)	15.00 (3.28)
n_1w_3	21.43 (3.81)	12.50 (3.05)	0.00 (1.00)
n_1w_4	75.00 (6.64)	25.00 (4.07)	0.00 (1.00)
n_1w_5	39.71 (6.12)	0.00 (1.00)	34.62 (5.89)
n_1w_6	40.91 (6.47)	35.00 (5.99)	5.77 (2.27)
n_2w_1	41.67 (6.50)	7.50 (2.50)	20.69 (3.76)
n_2w_2	21.43 (3.81)	0.00 (1.00)	50.00 (6.79)
n_2w_3	64.29 (8.02)	58.33 (7.68)	22.50 (4.78)
n_2w_4	12.50 (3.05)	14.29 (3.22)	0.00 (1.00)
n_2w_5	17.31 (4.22)	35.71 (6.03)	96.43 (9.86)
n_2w_6	42.00	37.50 (6.18)	45.65 (6.67)
SEm (±)	2.37	1.64	1.31
CD(0.05)	NS	5.112	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Relative Density of Sedges

Variations in the relative density of sedges due to the treatments are furnished in Tables 19a and 19b.

Data on relative density of sedges revealed no significant influence of both nitrogen management and weed management practices and also their interaction.

Table 19a. Effect of nitrogen management and weed management practices on relative density of sedges at 15, 30 and 45 DAS, per cent.

Treatments	Relative density of sedges		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	20.41 (3.75)	22.49 (3.75)	51.14 (6.27)
n_2 -100% N as urea as per KAU POP	23.22 (4.01)	38.87 (4.01)	44.22 (5.59)
SEm (±)	0.84	0.71	1.00
CD (0.05)	NS	NS	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha-1	28.33 (4.18)	11.25 (4.18)	43.85 (5.45)
w_2 -PE Oxyfluorfen at 0.15 kg ha-1	27.68 (4.83)	59.57 (4.83)	45.00 (5.86)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	20.41 (3.66)	15.63 (3.66)	46.67 (6.18)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	31.25 (4.46)	41.07 (4.46)	77.01 (8.75)
w_5 - HW at 15 and 30 DAS	16.80 (3.76)	44.05 (3.76)	5.36 (1.93)
w_6 - Weedy check	6.41 (2.35)	12.50 (2.35)	68.23 (7.39)
SEm (±)	1.45	1.23	1.73
CD (0.05)	NS	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Table 19b. Interaction effect of nitrogen management and weed management practices on in relative density of sedges at 15, 30 and 45 DAS, per cent.

Interactions	Relative density of sedges		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	15.00 (3.28)	0.00 (1.00)	20.46 (4.57)
n_1w_2	12.50 (3.05)	12.00 (3.61)	80.00 (8.93)
n_1w_3	28.57 (4.31)	6.25 (2.34)	33.33 (4.61)
n_1w_4	37.50 (4.85)	25.00 (4.07)	69.23 (8.26)
n_1w_5	22.06 (4.57)	66.67 (7.96)	0.00 (1.00)
n_1w_6	6.82 (2.41)	25.00 (5.08)	103.85 (10.22)
n_2w_1	41.67 (5.09)	22.50 (3.89)	67.24 (6.32)
n_2w_2	42.86 (6.62)	107.14 (10.28)	10.00 (2.79)
n_2w_3	12.25 (3.02)	25.00 (4.07)	60.00 (7.75)
n_2w_4	25.00 (4.07)	57.14 (7.38)	84.78 (9.26)
n_2w_5	11.54 (2.95)	21.43 (4.67)	10.71(2.87)
n_2w_6	6.00 (2.30)	0.00 (1.00)	32.61(4.57)
SEm (±)	2.05	1.74	2.45
CD(0.05)	NS	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Relative Density of Broad Leaf Weeds

The main and interaction effects of nitrogen and weed management practices on relative density of broad leaf weeds are presented in tables 20a and 20b.

Data showed no significant influence of nitrogen management practices on relative density of broad leaf weeds (BLW).

Relative density of BLW was significantly influenced by weed management practices only at 15 DAS. Among the weed control techniques, least density of grasses was observed in w_4 (0.00 %). NxW interaction effect was found to be not significant.

Table 20a. Effect of nitrogen management and weed management practices on relative density of BLW at 15, 30 and 45 DAS, per cent.

Treatments	Relative density of BLW		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	42.79 (5.90)	58.60 (7.16)	51.14 (6.27)
n_2 -100% N as urea as per KAU POP	33.27 (5.34)	39.84 (6.19)	44.22 (5.59)
SEm (±)	0.50	0.81	0.99
CD (0.05)	NS	NS	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	38.33 (7.81)	61.25 (7.85)	43.85 (5.45)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	50.89 (4.86)	29.04 (5.08)	45.00 (5.86)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	36.22 (6.03)	44.79 (6.56)	46.67 (6.18)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	0.00 (1.00)	42.86 (5.78)	77.01 (8.76)
w_5 - HW at 15 and 30 DAS	50.23 (7.26)	64.88 (7.80)	5.36 (1.93)
w_6 - Weedy check	52.50 (5.54)	52.50 (6.99)	68.23 (7.40)
SEm (±)	0.87	1.40	1.731
CD (0.05)	2.702	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Table 20b. Interaction effect of nitrogen management and weed management practices on in relative density of BLW at 15, 30 and 45 DAS, per cent.

Interactions	Relative density of BLW		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	60.00 (7.81)	70.00 (8.41)	20.46 (4.57)
n_1w_2	37.50 (4.86)	42.00 (6.08)	80.00 (8.93)
n_1w_3	35.71 (6.03)	56.25 (7.25)	33.33 (4.61)
n_1w_4	0.00 (1.00)	50.00 (5.53)	69.23 (8.26)
n_1w_5	48.53 (6.97)	58.33 (7.13)	0.00 (1.00)
n_1w_6	75.00 (8.71)	75.00 (8.60)	103.85 (10.22)
n_2w_1	16.67 (4.20)	52.50 (7.30)	67.24 (6.32)
n_2w_2	64.29 (7.97)	16.07 (4.08)	10.00 (2.79)
n_2w_3	36.74 (6.06)	33.33 (5.86)	60.00 (7.75)
n_2w_4	0.00 (1.00)	35.71 (6.03)	84.78 (9.26)
n_2w_5	51.92 (7.26)	71.43 (8.47)	10.71 (2.87)
n_2w_6	30.00 (5.54)	30.00 (5.39)	32.61 (4.57)
SEm (±)	1.23	1.98	2.45
CD (0.05)	NS	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

4.2.6 Relative Weed Biomass

The main and interaction effects of nitrogen and weed management on relative weed biomass of grasses, sedges and broad leaf weeds are detailed in Tables 21a, 21b, 22a, 22b, 23a, and 23b.

Relative Weed Biomass of Grasses

Data on relative biomass of grasses has revealed that it was significantly altered by nitrogen management practices at 15 and 45 DAS (Tables 21a and 21b).

Nitrogen management, n_1 resulted in lower relative biomass of grasses at 15 (13.07 %) and 45 DAS (9.44 %) compared to n_2 (26.12 % and 31.01 %, respectively)

The results showed that weed management practices had significantly changed relative biomass of grasses at 15, 30 and 45 DAS. At 15 DAS, biomass of grasses observed was lower in w_2 (2.96 %) and it was on a par with w_4 (5.57 %). At 30 DAS, biomass of grasses observed was lower in w_4 (9.80 %) and it was on par with w_5 (9.90 %), w_2 (19.85 %), and w_1 (19.94 %). However, at 45 DAS, biomass of grasses was observed lower in w_4 (0.33 %) and it was on par with w_3 (14.30 %).

The first order interaction effects were found to be significant with respect to relative biomass of grasses only at 30 DAS. Among the combinations, biomass of grasses was lower in n_2w_2 (0.33 %) which was on a par with n_1w_5 (1.37 %), n_1w_4 (7.00 %), n_2w_4 (12.61 %) and n_2w_1 (14.30 %).

Table 21a. Effect of nitrogen management and weed management practices on relative biomass of grasses at 15, 30 and 45 DAS, per cent.

Treatments	Relative biomass of grasses		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	13.07 (3.51)	21.97 (4.19)	9.44 (2.79)
n_2 -100% N as urea as per KAU POP	26.12 (5.71)	20.31 (4.08)	31.01 (4.83)
SEm (±)	0.60	0.43	0.44
CD (0.05)	1.877	NS	1.29
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	24.86 (5.44)	19.94 (4.41)	23.11 (4.39)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	2.96 (1.71)	19.85 (3.56)	17.06 (3.60)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	28.54 (5.93)	33.82 (5.08)	14.30 (2.82)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	5.57 (2.17)	9.80 (2.46)	0.33 (1.00)
w_5 - HW at 15 and 30 DAS	20.56 (5.25)	9.90 (3.33)	44.04 (6.44)
w_6 - Weedy check	35.08 (7.13)	33.73 (5.97)	22.50 (4.59)
SEm (±)	1.05	0.75	0.76
CD (0.05)	3.252	2.204	2.236

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Table 21b. Interaction effect of nitrogen management and weed management practices on relative biomass of grasses at 15, 30 and 45 DAS, per cent.

Interactions	Relative biomass of grasses		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	10.75 (3.28)	25.40 (4.84)	25.58 (2.59)
n_1w_2	1.00 (1.00)	39.54 (6.11)	4.89 (1.83)
n_1w_3	17.18 (4.10)	28.17 (4.69)	0.33 (1.00)
n_1w_4	0.33 (1.00)	7.00 (2.19)	0.33 (1.00)
n_1w_5	23.56 (5.49)	1.37 (2.04)	20.22 (3.74)
n_1w_6	25.62 (6.18)	30.32 (5.24)	5.28 (1.47)
n_2w_1	38.97 (7.60)	14.30 (3.97)	20.64 (1.91)
n_2w_2	4.91 (2.42)	0.33 (1.00)	29.23 (1.42)
n_2w_3	39.89 (7.77)	39.47 (5.47)	28.26 (2.23)
n_2w_4	10.81 (3.35)	12.61 (2.72)	0.33 (1.00)
n_2w_5	17.56 (5.01)	18.03 (4.62)	67.87 (4.40)
n_2w_6	44.55 (8.07)	37.13 (6.69)	39.71 (2.83)
SEm (±)	1.48	1.06	1.08
CD(0.05)	NS	3.118	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Relative Weed Biomass of Sedges

Data on relative biomass of sedges revealed that it was not significantly modified by both nitrogen management and weed management practices and their interaction (Tables 22a and 22b).

Table 22a. Effect of nitrogen management and weed management practices on relative biomass of sedges at 15, 30 and 45 DAS, per cent.

Treatments	Relative biomass of sedges		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	18.43 (3.52)	9.82 (3.01)	30.62 (4.73)
n_2 -100% N as urea as per KAU POP	18.21 (3.70)	16.72 (3.56)	26.47 (4.17)
SEm (±)	0.77	0.47	0.74
CD (0.05)	NS	NS	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha-1	13.09 (3.08)	3.81 (2.09)	26.06 (4.43)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	22.10 (4.26)	29.85 (4.76)	22.22 (4.10)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	7.52 (2.47)	2.29 (1.43)	30.22 (4.38)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	42.14 (5.10)	22.63 (4.20)	58.49 (6.54)
w_5 - HW at 15 and 30 DAS	19.94 (4.55)	11.49 (3.92)	1.29 (1.96)
w_6 - Weedy check	5.15 (2.18)	9.55 (3.30)	32.99 (5.30)
SEm (±)	1.35	0.81	1.27
CD (0.05)	NS	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Table 22b. Interaction effect of nitrogen management and weed management practices on relative biomass of sedges at 15, 30 and 45 DAS, per cent.

Interactions	Relative biomass of sedges		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	16.90 (3.45)	0.75 (1.41)	17.78 (4.18)
n_1w_2	12.34 (3.03)	8.48 (3.33)	36.20 (5.88)
n_1w_3	10.17 (2.81)	0.33 (1.00)	21.36 (3.34)
n_1w_4	50.00 (5.53)	16.67 (3.68)	49.98 (6.04)
n_1w_5	16.25 (4.15)	15.36 (4.48)	1.37 (2.04)
n_1w_6	4.94 (2.15)	17.30 (4.13)	57.00 (6.88)
n_2w_1	9.27 (2.71)	6.86 (2.77)	34.33 (4.68)
n_2w_2	31.86 (5.49)	51.21 (6.19)	8.24 (2.32)
n_2w_3	4.87 (2.14)	4.25 (1.86)	39.08 (5.42)
n_2w_4	34.28 (4.67)	28.60 (4.72)	67.00 (7.03)
n_2w_5	23.64 (4.96)	7.63 (3.37)	1.20 (1.87)
n_2w_6	5.37 (2.21)	1.80 (2.46)	8.97 (3.71)
SEm (±)	1.90	1.15	1.80
CD (0.05)	NS	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Relative Weed Biomass of Broad Leaf Weeds

Perusal of the data on the effect of nitrogen management practices on relative biomass of broad leaf weeds indicated that it was not significantly affected by nitrogen management practices (Tables 23a and 23b).

Weed management practices significantly altered the relative biomass of broad leaf weeds at 15 and 30 DAS. At 15 DAS, relative biomass of broad leaf weeds was lower most in the w_4 (0.33 %). At 30 DAS, relative biomass of broad leaf weeds was lower in w_2 (18.89 %) and it was on a par with w_3 (21.55 %), w_4 (25.23 %), and w_6 (27.21 %).

N x W interaction effect was also found to be not significant with respect to relative biomass of broad leaf weeds.

Table 23a. Effect of nitrogen management and weed management practices on relative biomass of broad leaf weeds at 15, 30 and 45 DAS, per cent

Treatments	Relative biomass of broad leaf weeds		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	31.71 (4.82)	37.15 (5.65)	23.32 (4.25)
n_2 -100% N as urea as per KAU POP	24.54 (4.58)	32.13 (5.34)	11.69 (2.97)
SEm (±)	0.50	0.27	0.49
CD (0.05)	NS	NS	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	34.84 (5.61)	45.63 (6.35)	20.12 (4.18)
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	33.72 (4.91)	18.89 (4.20)	29.39 (5.06)
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	33.79 (4.94)	21.55 (4.91)	6.49 (1.86)
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	0.33 (1.00)	25.23 (5.09)	8.84 (2.04)
w_5 - HW at 15 and 30 DAS	35.39 (6.03)	49.34 (6.98)	25.20 (4.46)
w_6 - Weedy check	30.69 (5.69)	27.21 (5.46)	15.00 (4.08)
SEm (±)	0.86	0.46	0.85
CD (0.05)	2.519	1.344	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

Table 23b. Interaction effect of nitrogen management and weed management practices on relative biomass of broad leaf weeds at 15, 30 and 45 DAS, per cent.

Interactions	Relative biomass of broad leaf weeds		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	46.17 (6.29)	42.76 (6.08)	25.54 (4.87)
n_1w_2	26.11 (4.24)	21.65 (4.77)	28.58 (5.29)
n_1w_3	43.38 (5.51)	39.16 (5.46)	12.64 (2.72)
n_1w_4	0.33 (1.00)	44.00 (5.77)	17.35 (3.07)
n_1w_5	35.02 (6.03)	54.06 (7.33)	49.20 (7.06)
n_1w_6	39.25 (5.85)	21.28 (4.51)	6.62 (2.52)
n_2w_1	23.51 (4.93)	48.50 (6.62)	14.69 (3.50)
n_2w_2	41.24 (5.58)	16.12 (3.63)	30.20 (4.84)
n_2w_3	24.19 (4.37)	23.94 (4.35)	0.33 (1.00)
n_2w_4	0.33 (1.00)	26.46 (4.41)	0.33 (1.00)
n_2w_5	35.76 (6.03)	44.62 (6.62)	1.20 (1.87)
n_2w_6	22.13 (5.54)	33.13 (6.41)	23.37 (5.64)
SEm (±)	1.22	0.65	1.21
CD(0.05)	NS	NS	NS

(The data were subjected to square root transformation and transformed values are given in parenthesis).

4.3 PHYSIOLOGICAL PARAMETERS

4.3.1 *Total Chlorophyll Content*

Results on the effect of nitrogen management, weed management and their interaction on total chlorophyll content are shown in Tables 24a and 24b.

Data on total chlorophyll content showed that it was significantly impacted by nitrogen management practices at 30 DAS. Nitrogen management, n_1 resulted in the highest chlorophyll content (2.15 mg g^{-1}) compared to n_2 (1.73 mg g^{-1}).

Weed management practices also had significant influence on total chlorophyll content of leaves at 30 DAS. Amid the weed control strategies, the treatment w_2 was found to be significantly superior to other treatments and it has recorded the highest chlorophyll content of 3.12 mg g^{-1} of leaves.

NxW interaction was also found to be significant in total chlorophyll content of leaves at 30 DAS. Among the treatment combinations, n_1w_5 recorded the highest chlorophyll content (3.42 mg g^{-1}) and it was on par with n_2w_2 (3.16 mg g^{-1}), n_1w_2 (3.08 mg g^{-1}), n_2w_3 (2.90 mg g^{-1}), n_1w_6 (2.81 mg g^{-1}), and n_2w_1 (2.63 mg g^{-1}). Chlorophyll content was recorded lower in n_2w_6 (0.45 mg g^{-1}) which was on a par with n_2w_5 (0.48 mg g^{-1}), n_1w_1 (0.50 mg g^{-1}), n_2w_4 (0.74 mg g^{-1}) and n_1w_3 (0.79 mg g^{-1}).

Table 24a. Effect of nitrogen management and weed management practices on total chlorophyll content in okra, mg g^{-1} (on fresh weight basis)

Treatments	Total chlorophyll	
	30 DAS	60 DAS
Nitrogen management (N)		
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	2.15	2.51
n_2 -100% N as urea as per KAU POP	1.73	2.55
SEm (±)	0.12	0.05
CD (0.05)	0.375	NS
Weed management (W)		
w_1 -PE Pendimethalin at 1 kg ha^{-1}	1.57	2.65
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	3.12	2.34
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	1.84	2.58
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	1.51	2.61
w_5 - HW at 15 and 30 DAS	1.95	2.52
w_6 - Weedy check	1.63	2.48
SEm (±)	0.21	0.09
CD (0.05)	0.650	NS

Table 24b. Interaction effect of nitrogen management and weed management practices on total chlorophyll content in okra, mg g^{-1} (on fresh weight basis)

Interactions	Total chlorophyll	
	30 DAS	60 DAS
N x W interaction		
n_1w_1	0.50	2.57
n_1w_2	3.08	2.34
n_1w_3	0.79	2.56
n_1w_4	2.29	2.53
n_1w_5	3.42	2.52
n_1w_6	2.81	2.51
n_2w_1	2.63	2.74
n_2w_2	3.16	2.33
n_2w_3	2.90	2.59
n_2w_4	0.74	2.69
n_2w_5	0.48	2.52
n_2w_6	0.45	2.45
SEm (±)	0.30	0.12
CD(0.05)	0.920	NS

4.3.2 Nitrogen Use Efficiency

4.3.2.1 Partial Factor Productivity

Results of partial factor productivity of nitrogen are presented in Tables 25a and 25b.

Data on partial factor productivity revealed that it was significantly altered by nitrogen management practices. Nitrogen management with nano urea (n_1) gave maximum partial factor productivity of 42.00 kg kg^{-1} N compared to n_2 (14.51 kg kg^{-1}).

Perusal of the data on the influence of weed management practices on a partial factor productivity showed its significant effect. Amid the weed management approaches, the highest partial factor productivity of 47.14 kg kg^{-1} nitrogen was noticed in w_5 which was found to be significantly superior among others. This was followed by w_3 (40.24 kg kg^{-1}) and w_1 (34.36 kg kg^{-1}). The partial factor productivity was least recorded in w_2 (12.32 kg kg^{-1}).

N x W interaction effect was also found to be significant in partial factor productivity of nitrogen. The highest partial factor productivity was recorded in the combination n_1w_5 (73.15 kg kg^{-1}) which was significantly superior. This was followed by n_1w_3 (61.79 kg kg^{-1}) and n_1w_1 (52.87 kg kg^{-1}). The partial factor productivity was observed lowest in n_2w_2 (8.67 kg kg^{-1}) which was on par with n_2w_6 (10.84 kg kg^{-1}) and n_2w_4 (11.36 kg kg^{-1}).

4.3.2.2 Agronomic Efficiency

Results of agronomic efficiency of nitrogen are presented in Tables 25a and 25b.

Perusal of the data revealed the significant influence of nitrogen management practices on agronomic efficiency. Nitrogen management with nano urea, n_1 (20.32 kg kg^{-1}) resulted in higher agronomic efficiency compared to n_2 (7.35 kg kg^{-1}).

Weed management practices also had significant influenced on agronomic efficiency. The highest agronomic efficiency of nitrogen was recorded in w_5 (36.02 kg kg^{-1}) which was found to be significantly superior among others. This was followed by w_3 (27.90 kg kg^{-1}) and w_1 (21.16 kg kg^{-1}). The least agronomic efficiency was indicated by w_2 (-5.02 kg kg^{-1}). Weedy check recorded an agronomic efficiency of 0.18 kg kg^{-1}.

N x W interaction had significant influence on the agronomic efficiency of nitrogen. The highest agronomic efficiency was recorded in n_1w_5 (51.47 kg kg^{-1}) which was significantly superior. This was followed by n_1w_3 (40.11 kg kg^{-1}) and n_1w_1 (31.20 kg kg^{-1}). Agronomic efficiency was observed lower in n_1w_2 (-5.70 kg kg^{-1}) which was on a par with n_2w_2 (-4.33 kg kg^{-1}) and n_2w_6 (0.00 kg kg^{-1}).

4.3.2.3 Physiological Efficiency

The main and interaction effects of nitrogen and weed management on physiological efficiency of nitrogen are presented in Tables 25a and 25b.

Data on physiological efficiency showed no significant difference with respect to effect of nitrogen management and weed management practices. The interaction effect was also found to be non-significant.

4.3.2.4 Apparent Recovery Efficiency

The variations in apparent recovery efficiency of nitrogen due to treatments are presented in Tables 25a and 25b.

Data on apparent recovery efficiency revealed that it was significantly impacted by nitrogen management practices. Nitrogen management using nano urea, n_1 resulted in higher agronomic efficiency (40.90 %) of nitrogen compared to n_2 (14.38 %).

Perusal of the data revealed the significant influence of weed management practices on apparent recovery efficiency. Amongst the weed management techniques, the highest apparent recovery efficiency of nitrogen was recorded in w_5 (89.09 %) which was significantly superior. This was followed by w_3 (50.60 %) and w_1 (45.87 %). Apparent recovery efficiency was recorded lower by w_2 (-13.44 %) which was on a par with w_4 (-5.28 %).

N x W interaction effect was also found to be significant with respect to apparent recovery efficiency of nitrogen. The highest apparent recovery efficiency was recorded in n_1w_5 (131.30 %) which was significantly superior. This was followed by n_1w_1 (92.11 %) and n_1w_3 (62.62 %). Lowest was observed in n_1w_2 (-25.89 %) which was on par with n_1w_4 (-12.74 %).

Table 25a. Effect of nitrogen management and weed management practices on nitrogen use efficiency in okra

Treatments	Nitrogen use efficiency			
	Partial factor productivity (kg kg^{-1})	Agronomic efficiency (kg kg^{-1})	Physiological efficiency (kg kg^{-1})	Apparent recovery efficiency (%)
Nitrogen management (N)				
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	42.00	20.32	20.90	40.90
n_2 -100% N as urea as per KAU POP	14.51	7.35	96.94	14.38
SEm (±)	0.50	0.79	70.32	2.03
CD (0.05)	1.551	2.453	NS	6.330
Weed management (W)				
w_1 -PE Pendimethalin at 1 kg ha^{-1}	34.63	21.16	106.67	45.87
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	12.32	-5.02	180.15	-13.44
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	40.24	27.90	42.36	50.60
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	18.75	2.76	-17.04	-5.28
w_5 - HW at 15 and 30 DAS	47.14	36.02	30.59	89.09
w_6 - Weedy check	16.44	0.18	10.78	-1.01
SEm (±)	0.86	1.37	121.80	3.52
CD (0.05)	2.69	4.249	NS	10.96

Table 25b. Interaction effect of nitrogen management and weed management practices on nitrogen use efficiency in okra

Interactions	Nitrogen use efficiency			
	Partial factor productivity (kg kg^{-1})	Agronomic efficiency (kg kg^{-1})	Physiological efficiency (kg kg^{-1})	Apparent recovery efficiency (%)
N x W interaction				
n_1w_1	52.87	31.20	33.87	92.11
n_1w_2	15.97	-5.70	22.18	-25.89
n_1w_3	61.79	40.11	64.28	62.62
n_1w_4	26.15	4.47	-55.97	-12.74
n_1w_5	73.15	51.47	39.46	131.30
n_1w_6	22.04	0.36	21.57	-2.03
n_2w_1	16.40	11.12	179.47	-0.38
n_2w_2	8.67	-4.33	338.13	-0.98
n_2w_3	18.68	15.69	20.43	38.58
n_2w_4	11.36	1.04	21.89	2.19
n_2w_5	21.13	20.57	21.71	46.88
n_2w_6	10.84	0.00	0.00	0.00
SEm (±)	1.22	1.93	172.24	4.98
CD(0.05)	3.798	6.009	NS	15.504

4.4 QUALITY PARAMETERS OF FRUIT

4.4.1 Crude Protein Content

Results on the effect of nitrogen management, weed management and their interaction on crude protein content of fruit are detailed in Tables 26a and 26b.

Data on crude protein content indicated that it was significantly changed by nitrogen management practices. Nitrogen management, n_2 produced the highest crude protein content (17.16 %) compared to n_1 (13.05 %).

Weed management practices also had significant influence on crude protein content of fruits. Amongst the weed control practices, the treatment w_2 produced the highest crude protein content of 16.53 per cent and it was statistically on par with w_3 (16.24 %), w_5 (16.01 %) and w_6 (15.25 %).

NxW interaction was also found significant in crude protein content. Among the treatment combinations, n_2w_3 recorded the highest crude protein content (21.35 %) and it was on par with n_2w_5 (21.00 %), n_2w_2 (19.60 %) and n_1w_1 (18.58 %).

4.4.2 Crude Fibre Content

Results on the effect of nitrogen management, weed management and their interaction on crude fibre content of fruit are detailed in Tables 26a and 26b.

Data on crude fibre content revealed that it was significantly affected by nitrogen management practices. Nitrogen management, n_1 resulted in the highest crude fibre content (33.36 %) compared to n_2 (29.07 %).

Weed management practices significantly impacted crude fibre content. The highest crude fibre content was produced by the treatment w_5 (35.05 %) and it was on par with w_3 (33.22 %) and w_1 (32.13).

NxW interaction was found significant in crude fibre content. Among the treatment combinations, n_1w_5 was found to be significantly superior and it has recorded a crude fibre content of 39.29 %. It was followed by n_1w_4 (34.80 %) and n_1w_3 (34.78 %).

4.4.3 Ascorbic acid

Results on the effect of nitrogen management, weed management and their interaction on ascorbic acid content of fruit are detailed in Tables 26a and 26b.

Data on ascorbic acid content showed that it was significantly impacted by nitrogen management practices. Nitrogen management, n_1 resulted in the highest ascorbic acid content (22.00 mg per 100 g) compared to n_2 (20.69 mg per 100 g).

Weed management practices also had significant influence on total ascorbic acid content of fruits at 30 DAS. Within the weed management practices, the treatment w_5 was found to be significantly superior to other treatments and it has resulted in the highest ascorbic acid content (25.04 mg per 100 g) of fruits. Least was produced by the w_6 (18.28 mg per 100 g) and it was on par with w_2 (19.02 mg per 100 g).

NxW interaction was also found significant in ascorbic acid content of fruits. Among the treatment combinations, n_1w_5 has recorded the highest ascorbic acid content (27.39 per 100 g) and it was on par with n_2w_1 (26.42 mg per 100 g).

Table 26a. Effect of nitrogen management and weed management practices on quality parameters of okra

Treatments	Quality parameters		
	Crude protein (%)	Crude fibre (%)	Ascorbic acid (mg per 100g)
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	13.05	33.36	22.00
n_2 -100% N as urea as per KAU POP	17.16	29.07	20.69
SEm (±)	0.45	0.82	0.33
CD (0.05)	1.393	2.405	1.017
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	13.86	32.13	22.89
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	16.53	29.47	19.02
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	16.24	33.22	21.54
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	12.74	30.68	21.33
w_5 - HW at 15 and 30 DAS	16.01	35.05	25.04
w_6 - Weedy check	15.25	26.74	18.28
SEm (±)	0.78	1.42	0.57
CD (0.05)	2.41	4.165	1.761

Table 26b. Interaction effect of nitrogen management and weed management practices on quality parameters of okra

Interactions	Quality parameters		
	Crude protein (%)	Crude fibre (%)	Ascorbic acid (mg per 100g)
NxW interaction			
n_1w_1	18.58	34.41	19.36
n_1w_2	13.45	29.79	19.01
n_1w_3	11.13	34.78	22.88
n_1w_4	10.08	34.80	24.87
n_1w_5	11.03	39.29	27.39
n_1w_6	14.05	27.13	18.52
n_2w_1	9.15	29.85	26.42
n_2w_2	19.60	29.16	19.04
n_2w_3	21.35	31.66	20.21
n_2w_4	15.40	26.57	17.79
n_2w_5	21.00	30.82	22.69
n_2w_6	16.45	26.35	18.04
SEm (±)	1.10	1.06	0.80
CD(0.05)	3.414	3.308	2.491

4.5 ENZYME ANALYSIS

4.5.1 Dehydrogenase Enzyme Activity

Results of dehydrogenase enzyme activity in soil at 15, 30 and 45 DAS are presented in Tables 27a and 27b.

Data on dehydrogenase enzyme activity in soil showed that it was not significantly modified by nitrogen management practices.

Weed management practices also had significant influence on dehydrogenase enzyme activity in soil at 15, 30 and 45 DAS. At 15 DAS, the treatment w_3 resulted in the highest dehydrogenase enzyme activity in soil (134.7 μg triphenyl formazan (TPF) g^{-1}soil day^{-1}) which was on par with the treatments w_5 (132.8 μg TPF g^{-1}soil d^{-1}), w_1 (116.2 μg TPF g^{-1}soil d^{-1}) and w_6 (110.7 μg TPF g^{-1}soil d^{-1}). However, at 30 DAS, w_5 resulted in the highest dehydrogenase enzyme activity in soil (98.9 μg TPF g^{-1}soil d^{-1}) which was on par with w_3 (91.1 μg TPF g^{-1}soil d^{-1}) and w_6 (81.7 μg TPF g^{-1}soil d^{-1}). At 45 DAS, w_5 recorded the highest dehydrogenase enzyme activity in soil (76.1 μg triphenyl formazan (TPF) g^{-1}soil d^{-1}) and it was found to be significantly superior among the others.

The effect of NxW interaction was also found to be significant with respect to dehydrogenase enzyme activity in soil at all the growth stages. At 15 DAS, the treatment combination n_1w_5 had the highest dehydrogenase enzyme activity in soil (165.0 μg TPF g^{-1}soil d^{-1}) which was on par with n_1w_3 (146.1 μg TPF g^{-1}soil d^{-1}). The dehydrogenase enzyme activity was recorded lower by n_1w_4 (65.4 μg TPF g^{-1}soil d^{-1}) which was on par with n_2w_2, n_1w_2 and n_2w_4. At 30 DAS and 45 DAS also, the treatment combination n_1w_5 had the highest dehydrogenase enzyme activity in soil (128.8 and 99.4 μg TPF g^{-1}soil d^{-1} respectively) and it was found to be significantly superior among the others. At 30 DAS, the dehydrogenase enzyme activity was recorded lower by n_2w_2 (36.6 μg TPF g^{-1}soil d^{-1}) which was on par with n_1w_4, n_2w_2, n_1w_2 and n_2w_4. At 45 DAS, the dehydrogenase enzyme activity recorded was lower in soil by n_2w_2 (12.3 μg TPF g^{-1}soil d^{-1}) which was on par with n_1w_2, n_2w_4, n_1w_2 and n_1w_4.

Table 27a. Effect of nitrogen management and weed management practices on dehydrogenase enzyme activity, µg triphenyl formazan (TPF) g^{-1}soil d^{-1}

Treatments	Dehydrogenase enzyme activity		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	113.4	76.5	51.1
n_2 -100% N as urea as per KAU POP	101.6	69.6	44.3
SEm (±)	4.7	3.4	3.0
CD (0.05)	NS	NS	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	116.2	79.9	49.1
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	73.8	38.7	14.8
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	134.7	91.1	52.3
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	77.1	48.2	37.5
w_5 - HW at 15 and 30 DAS	132.8	98.9	76.1
w_6 - Weedy check	110.7	81.7	56.3
SEm (±)	8.2	5.8	5.2
CD (0.05)	25.41	18.13	16.3

Table 27b. Interaction effect of nitrogen management and weed management practices on dehydrogenase enzyme activity, µg triphenyl formazan (TPF) g^{-1}soil d^{-1}

Interactions	Dehydrogenase enzyme activity		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	128.9	91.5	68.3
n_1w_2	74.3	40.9	17.5
n_1w_3	146.1	84.9	35.3
n_1w_4	65.4	39.2	39.2
n_1w_5	165	128.8	99.4
n_1w_6	101	73.6	46.9
n_2w_1	103.6	68.2	30
n_2w_2	73.2	36.6	12.3
n_2w_3	123.2	97.3	69.4
n_2w_4	88.8	57.3	35.8
n_2w_5	100.6	68.9	52.8
n_2w_6	120.5	89.8	65.8
SEm (±)	8.2	8.2	5.24
CD(0.05)	25.41	25.64	16.3

4.5.2 Urease Enzyme Activity

Results of urease enzyme activity on soil at 15, 30 and 45 DAS are presented in Tables 28a and 28b.

Data on urease enzyme activity in soil showed that it was significantly impacted by nitrogen management practices at all the growth stages. The urease enzyme activity showed an increasing trend from 15 to 30 DAS and a decline later at 45 DAS irrespective of the treatments. Nitrogen management, n_1 resulted in the highest urease enzyme activity in soil at 15, 30 and 45 DAS (59.39, 78.12, 41.16 µg urea hydrolyzed g^{-1}soil $4h^{-1}$) compared to n_2 at 15, 30 and 45 DAS (52.18, 70.88, 34.44 μg urea hydrolyzed g^{-1}soil $4h^{-1}$) respectively.

Weed management practices also had significant influence on urease enzyme activity in soil at 15, 30 and 45 DAS. At 15 DAS, the treatment w_5 has produced the highest urease enzyme activity in soil (72.36 μg urea hydrolyzed g^{-1}soil $4h^{-1}$) which was on par with the treatment w_3 (71.14 μg urea hydrolyzed g^{-1}soil $4h^{-1}$). However, at 30 DAS, w_5 has produced the highest urease enzyme activity in soil (98.68 μg urea hydrolyzed g^{-1}soil $4h^{-1}$) and it was found to be significantly superior among the others. At 45 DAS, w_5 has recorded the highest urease enzyme activity in soil (50.08 μg urea hydrolyzed g^{-1}soil $4h^{-1}$) and it was found to be significantly superior among the others.

NxW interaction was also found to be significant in terms of urease enzyme activity in soil at all the growth stages. At 15 DAS, the treatment combination n_1w_5 generated the highest urease enzyme activity in soil (78.05 μg urea hydrolyzed g^{-1}soil $4h^{-1}$) which was on par with n_1w_3 (77.41 μg urea hydrolyzed g^{-1}soil $4h^{-1}$). At 30 DAS and 45 DAS also, the treatment combination n_1w_5 has presented the highest dehydrogenase enzyme activity In soil (109.27 and 57.14 μg urea hydrolyzed g^{-1}soil $4h^{-1}$respectively) and it was found to be significantly superior among the others.

Table 28a. Effect of nitrogen management and weed management practices on urease enzyme activity, µg urea hydrolyzed g^{-1}soil $4h^{-1}$.

Treatments	Urease enzyme activity		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	59.39	78.12	41.16
n_2 -100% N as urea as per KAU POP	52.18	70.88	34.44
SEm (±)	1.07	1.10	0.70
CD (0.05)	3.33	3.43	2.167
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	61.78	81.90	42.64
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	39.94	57.34	29.39
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	71.14	92.01	45.74
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	43.07	59.77	28.00
w_5 - HW at 15 and 30 DAS	72.36	98.68	50.08
w_6 - Weedy check	46.43	57.31	30.94
SEm (±)	1.85	1.91	1.21
CD (0.05)	5.762	5.94	3.753

Table 28b. Interaction effects of nitrogen management and weed management practices on urease enzyme activity, µg urea hydrolyzed g^{-1}soil $4h^{-1}$.

Interactions	Urease enzyme activity		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	69.78	89.90	47.04
n_1w_2	40.42	59.82	27.25
n_1w_3	77.41	95.60	50.96
n_1w_4	44.92	56.45	32.22
n_1w_5	78.05	109.27	57.14
n_1w_6	45.78	57.68	32.34
n_2w_1	53.77	73.90	38.25
n_2w_2	39.47	54.87	31.53
n_2w_3	64.87	88.42	40.51
n_2w_4	41.22	63.09	23.77
n_2w_5	66.67	88.09	43.03
n_2w_6	47.09	56.94	29.54
SEm (±)	2.62	2.70	1.71
CD(0.05)	8.148	8.399	5.308

4.6 CHEMICAL ANALYSIS

4.6.1 Nitrogen Uptake by Crop

The influence of nitrogen and weed management practices on nitrogen uptake by haulm, fruit and total uptake by crop are presented in Tables 29a and 29b.

Nitrogen uptake by haulm and total uptake by plant was significantly enhanced by nitrogen management practices. However, N uptake by fruit was not significantly modified by nitrogen management practices. Nitrogen management, n_1 resulted in higher N uptake by haulm (32.49 kg ha^{-1}) and total N uptake (56.45 kg ha^{-1}) compared to n_2 (27.52 kg ha^{-1} and 49.77 kg ha^{-1}, respectively).

Nitrogen uptake by haulm, fruit and total N uptake were markedly influenced by weed management practices. Amongst the strategies for weed management, the highest N uptake by haulm (58.64 kg ha^{-1}), fruit (37.21 kg ha^{-1}) and total N uptake by crop (95.85 kg ha^{-1}) was produced by the treatment w_5 and it was significantly superior. Weedy check resulted in significantly the lowest uptake of N by haulm (18.73 kg ha^{-1}), fruit (14.68 kg ha^{-1}) and total N uptake (33.40 kg ha^{-1}).

The two-factor interaction N x W had significant influence on N uptake by fruit, haulm and total N uptake. The highest N uptake by haulm was recorded in n_1w_5 (70.71 kg ha^{-1}), which was found to be significantly superior among the others. The highest N uptake by fruit was offered by n_1w_1 (43.30 kg ha^{-1}) and it was statistically comparable with n_2w_5 (38.96 kg ha^{-1}), n_1w_5 (35.46 kg ha^{-1}) and n_2w_3 (35.16 kg ha^{-1}). The highest total N uptake was recorded in n_1w_5 (106.18 kg ha^{-1}) and it was significantly superior over other combinations.

Table 29a. Effect of nitrogen management and weed management practices on N uptake by okra, kg ha^{-1}

Treatments	N uptake by crop		
	Haulm	Fruit	Total
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	32.49	23.96	56.45
n_2 -100% N as urea as per KAU POP	27.52	22.26	49.77
SEm (±)	1.33	1.07	1.82
CD (0.05)	4.124	NS	5.666
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	30.82	28.26	59.08
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	14.11	12.19	26.30
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	39.68	32.72	72.39
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	18.05	13.61	31.66
w_5 - HW at 15 and 30 DAS	58.64	37.21	95.85
w_6 - Weedy check	18.73	14.68	33.40
SEm (±)	2.30	1.42	3.15
CD (0.05)	7.143	4.165	9.814

Table 29b. Interaction effect of nitrogen management and weed management practices on N uptake by okra, kg ha^{-1}

Interactions	N uptake by crop		
	Haulm	Fruit	Total
NxW interaction			
n_1w_1	41.33	43.30	84.62
n_1w_2	10.25	9.47	19.72
n_1w_3	38.12	30.28	68.40
n_1w_4	15.33	11.63	26.95
n_1w_5	70.71	35.46	106.18
n_1w_6	19.21	13.65	32.85
n_2w_1	20.32	13.23	33.54
n_2w_2	17.98	14.90	32.88
n_2w_3	41.24	35.16	76.40
n_2w_4	20.77	15.59	36.36
n_2w_5	46.57	38.96	85.53
n_2w_6	18.25	15.72	33.96
SEm (±)	3.30	2.62	4.46
CD(0.05)	10.278	3.308	13.879

4.6.2 Phosphorus Uptake by Crop

Results of phosphorus uptake by haulm, fruit and total uptake by crop are presented in Tables 30a and 30b.

Data on P uptake by haulm, fruit and total P uptake by plant has shown that it was significantly modified by nitrogen management practices. Nitrogen management, n_1 resulted in higher P uptake by haulm (9.31 kg ha^{-1}), fruit (8.41 kg ha^{-1}) and total P uptake (17.73 kg ha^{-1}) compared to n_2 (8.40 kg ha^{-1}, 7.71 kg ha^{-1} and 15.11 kg ha^{-1}, respectively).

Phosphorus uptake by haulm, fruit and total P uptake were markedly influenced by weed management practices. Amidst the weed control practices, the highest P uptake by haulm, fruit and total P uptake was recorded in the treatment w_5 (10.46 kg ha^{-1}, 8.83 kg ha^{-1} and 18.29 kg ha^{-1}, respectively) and it was on par with w_3 (9.11 kg ha^{-1}, 9.10 kg ha^{-1} and 18.22 kg ha^{-1}, respectively).

N x W interaction effect had significant influence on P uptake by fruit, haulm and total P uptake. The highest P uptake by haulm, fruit and total P uptake were recorded in n_1w_5 (12.84 kg ha^{-1}, 9.49 kg ha^{-1}, 22.33 kg ha^{-1} respectively) which were on par with n_2w_3.

Table 30a. Effect of nitrogen management and weed management practices on P uptake by okra, kg ha^{-1}

Treatments	P uptake by crop		
	Haulm	Fruit	Total
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	9.31	8.41	17.72
n_2 -100% N as urea as per KAU POP	8.40	7.71	15.11
SEm (±)	0.38	0.40	0.63
CD (0.05)	1.178	1.243	1.964
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	6.42	9.11	15.53
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	5.57	8.50	14.07
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	9.11	9.10	18.22
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	6.90	8.68	14.58
w_5 - HW at 15 and 30 DAS	10.46	8.83	18.29
w_6 - Weedy check	5.83	5.60	10.43
SEm (±)	0.66	0.69	1.09
CD (0.05)	2.041	2.153	3.402

Table 30b. Interaction effect of nitrogen management and weed management practices on P uptake by okra, kg ha^{-1}

Interactions	P uptake by crop		
	Haulm	Fruit	Total
NxW interaction			
n_1w_1	8.61	7.61	16.22
n_1w_2	6.32	2.07	8.39
n_1w_3	11.69	8.09	19.78
n_1w_4	8.15	3.59	11.74
n_1w_5	12.84	9.49	22.33
n_1w_6	6.29	2.75	9.02
n_2w_1	8.23	4.43	12.66
n_2w_2	4.81	2.17	6.98
n_2w_3	12.25	5.23	17.48
n_2w_4	5.66	2.74	8.40
n_2w_5	12.08	4.92	19.00
n_2w_6	5.37	2.57	7.94
SEm (±)	0.93	0.49	1.55
CD(0.05)	2.886	1.5225	4.811

4.6.3 Potassium Uptake by Crop

Variation in potassium uptake by haulm, fruit and total uptake by crop are presented in Tables 31a and 31b.

Data on K uptake by haulm, fruit and total K uptake by plant showed that it was significantly affected by nitrogen management practices. Nitrogen management, n_1 resulted in higher K uptake by haulm (31.93 kg ha^{-1}), fruit (39.07 kg ha^{-1}) and total K uptake (70.99 kg ha^{-1}) compared to n_2 (23.49 kg ha^{-1}, 20.45 kg ha^{-1} and 43.95 kg ha^{-1}, respectively).

Potassium uptake by haulm, fruit and total K uptake were markedly influenced by weed management practices. Within the practices for weed control, the highest K uptake by haulm (49.83 kg ha^{-1}) was recorded in the treatment w_5 and it was significantly superior to others. Similarly, the highest K uptake by fruit was produced by w_1 (45.72 kg ha^{-1}) and it was on par with the treatments w_5 (43.04 kg ha^{-1}) and w_3 (35.64 kg ha^{-1}). The highest total K uptake was produced by w_5 (92.87 kg ha^{-1}) which was on par with w_1 (82.58 kg ha^{-1}).

N x W interaction exerted significant influence on K uptake by fruit, haulm and total K uptake. The highest K uptake by haulm and total K uptake was registered in n_1w_5 (75.25 kg ha^{-1} and 139.54 kg ha^{-1}, respectively) which was found to be significantly superior to others. Similarly, the highest K uptake by fruit was produced by n_1w_3 (67.77 kg ha^{-1}) and it was statistically comparable with n_1w_5 (64.30 kg ha^{-1}) and n_1w_1 (53.41 kg ha^{-1}).

Table 31a. Effect of nitrogen management and weed management practices on K uptake by okra, kg ha^{-1}

Treatments	K uptake by crop		
	Haulm	Fruit	Total
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	31.93	39.07	70.99
n_2 -100% N as urea as per KAU POP	23.49	20.45	43.95
SEm (±)	1.83	0.82	1.82
CD (0.05)	5.695	2.405	5.666
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	36.86	45.72	82.58
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	7.59	22.93	30.51
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	30.63	35.64	66.26
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	22.13	15.37	37.50
w_5 - HW at 15 and 30 DAS	49.83	43.04	92.87
w_6 - Weedy check	19.23	15.87	35.10
SEm (±)	3.17	5.63	3.15
CD (0.05)	9.865	17.52	9.814

Table 31b. Interaction effect of nitrogen management and weed management practices on K uptake by okra, kg ha^{-1}

Interactions	K uptake by crop		
	Haulm	Fruit	Total
NxW interaction			
n_1w_1	40.68	53.41	94.08
n_1w_2	3.35	20.16	23.51
n_1w_3	33.36	67.77	101.12
n_1w_4	25.38	8.86	34.23
n_1w_5	75.25	64.30	139.54
n_1w_6	13.58	19.92	33.49
n_2w_1	33.05	38.04	71.09
n_2w_2	11.83	25.68	37.52
n_2w_3	27.90	3.50	31.40
n_2w_4	18.89	21.88	40.76
n_2w_5	24.42	21.79	46.20
n_2w_6	24.89	11.83	36.72
SEm (±)	4.48	2.62	4.46
CD(0.05)	13.951	24.78	13.879

4.6.4 Nitrogen Removal by Weeds

Tables 32a and 32b present the effects of nitrogen management and weed management on nitrogen removal by weeds.

Data on N removal by weeds showed that it was significantly impacted by nitrogen management practices at all the growth stages. Nitrogen management, n_2 resulted in higher N removal by weeds (25.01 kg ha^{-1}, 24.69 kg ha^{-1}, 19.08 kg ha^{-1}) compared to n_1 (15.94 kg ha^{-1}, 19.94 kg ha^{-1}, 14.13 kg ha^{-1}) at 15, 30 and 45 DAS, respectively.

Nitrogen removal by weeds was also significantly changed by weed management practices at 15, 30 and 45 DAS. At 15 DAS, the highest N removal by weeds was noticed in w_6 (50.70 kg ha^{-1}) and it was significantly superior. The removal of N by weeds was recorded lower in w_2 (8.80 kg ha^{-1}) and it was on par with w_1 (15.76 kg ha^{-1}). At 30 DAS, the highest N removal by weeds was observed in the treatment w_2 (31.02 kg ha^{-1}) which was on par with w_6 (28.26 kg ha^{-1}) and w_1 (25.39 kg ha^{-1}). However, the removal of N by weeds was observed lower in w_5 (3.84 kg ha^{-1}). At 45 DAS, the highest N removal by weeds was observed in the treatment w_2 (35.08 kg ha^{-1}) which was significantly superior. However, removal of N by weeds was observed lowest in w_4 (3.11 kg ha^{-1}) and it was on par with the treatment w_3 (5.61 kg ha^{-1}).

N x W interaction effect had significant influence on N removal by weeds at 15, 30 and 45 DAS. At 15 DAS, the highest N removal by weeds was recorded in n_2w_6 (51.53 kg ha^{-1}), which was found to be on par with n_1w_6 (49.87 kg ha^{-1}). At 30 DAS, the highest N removal by weeds was recorded in n_1w_2 (37.16 kg ha^{-1}) and it was statistically comparable with n_1w_6 (31.37 kg ha^{-1}) and n_2w_1 (27.24 kg ha^{-1}). However, at 45 DAS, the highest N removal by weeds was recorded in n_2w_2 (40.69 kg ha^{-1}) and it was on par with n_2w_1 (32.83 kg ha^{-1}) and n_1w_2 (29.48 kg ha^{-1}).

Table 32a. Effect of nitrogen management and weed management practices on N removal by weeds, kg ha^{-1}

Treatments	N removal by weeds		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	15.94	19.94	14.13
n_2 -100% N as urea as per KAU POP	25.01	24.69	19.08
SEm (±)	1.79	1.2	1.53
CD (0.05)	4.1	3.03	4.754
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	15.76	25.39	23.95
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	8.80	31.02	35.08
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	24.56	16.43	5.61
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} fb HW at 30 DAS	22.02	13.93	3.11
w_5 - HW at 15 and 30 DAS	31.01	3.84	11.59
w_6 - Weedy check	50.70	28.26	20.31
SEm (±)	3.10	2.08	2.65
CD (0.05)	9.661	6.471	8.234

Table 32b. Interaction effects of nitrogen management and weed management practices on N removal by weeds, kg ha^{-1}

Interactions	N removal by weeds		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	27.76	23.55	15.07
n_1w_2	11.80	37.16	29.48
n_1w_3	23.62	16.82	7.29
n_1w_4	12.20	7.98	2.35
n_1w_5	30.41	2.73	16.19
n_1w_6	49.87	31.37	14.41
n_2w_1	3.76	27.24	32.83
n_2w_2	5.79	24.87	40.69
n_2w_3	25.5	16.04	3.93
n_2w_4	31.85	19.88	3.87
n_2w_5	31.62	4.95	6.98
n_2w_6	51.53	25.16	26.20
SEm (±)	4.39	4.39	3.74
CD(0.05)	13.662	13.662	11.644

4.6.5 Phosphorus Removal by Weeds

The influence of nitrogen and weed management on phosphorus removal by weeds are presented in Tables 33a and 33b.

Data on P removal by weeds revealed that it varied significantly with nitrogen management practices only at 45 DAS. Nitrogen management, n_2 resulted in higher P removal by weeds (16.15 kg ha^{-1}) compared to n_1 (10.15 kg ha^{-1}). However, nitrogen management had no significant influence on P removal by weeds at 15 and 30 DAS.

Phosphorus removal by weeds was significantly altered by weed management practices at 30 and 45 DAS. At 30 and 45 DAS, the highest P removal by weeds was observed in w_2 (26.03 kg ha^{-1} and 43.75 kg ha^{-1} respectively) which was found to be significantly superior.

N x W interaction effect had significant influence on P removal by weeds at 45 DAS only. At 45 DAS, the highest P removal by weeds was recorded in n_2w_2 (49.28 kg ha^{-1}), which was found to be significantly superior among others.

Table 33a. Effect of nitrogen management and weed management practices on P removal by weeds, kg ha^{-1}

Treatments	P removal by weeds		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	7.79	11.98	10.15
n_2 -100% N as urea as per KAU POP	7.60	11.73	16.15
SEm (±)	1.11	1.00	1.04
CD (0.05)	NS	NS	3.236
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	7.16	8.41	5.52
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	9.42	26.03	43.75
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	6.10	6.98	2.47
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	10.38	8.96	6.39
w_5 - HW at 15 and 30 DAS	3.65	1.62	1.54
w_6 - Weedy check	9.48	19.11	19.24
SEm (±)	1.93	1.74	1.80
CD (0.05)	NS	5.406	5.605

Table 33b. Interaction effect of nitrogen management and weed management practices on P removal by weeds, kg ha^{-1}

Interactions	P removal by weeds		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	6.41	7.20	2.22
n_1w_2	11.18	31.24	38.22
n_1w_3	6.38	8.29	3.40
n_1w_4	11.08	7.73	6.88
n_1w_5	2.94	1.40	1.05
n_1w_6	8.76	15.99	9.12
n_2w_1	7.91	9.62	8.81
n_2w_2	7.66	20.82	49.28
n_2w_3	5.82	5.67	1.53
n_2w_4	9.69	10.20	5.90
n_2w_5	4.36	1.84	2.02
n_2w_6	10.19	22.24	29.37
SEm (±)	2.72	2.46	2.55
CD(0.05)	NS	NS	7.926

4.6.6 Potassium Removal by Weeds

The mean data on the effect of the different treatments on potassium removal by weeds are summarised in the Tables 34a and 34b.

Data on K removal by weeds showed that it was significantly affected by nitrogen management practices only at 15 DAS. Nitrogen management, n_1 resulted in higher K removal by weeds (27.70 kg ha^{-1}) compared to n_2 (20.64 kg ha^{-1}). However, nitrogen management had no significant influence on K removal by weeds at 30 and 45 DAS.

Potassium removal by weeds was also significantly modified by weed management practices at 15, 30 and 45 DAS. At 15 DAS, the highest K removal by weeds was observed in w_6 (53.23 kg ha^{-1}) which was on par with w_5 (48.51 kg ha^{-1}). Similarly at 30 DAS, the highest K removal by weeds was observed in w_2 (55.40 kg ha^{-1}) which was statistically comparable with the treatment w_6 (53.05 kg ha^{-1}). At 45 DAS, the highest K removal by weeds was noticed in w_2 (47.39 kg ha^{-1}) and it was significantly superior among others.

N x W interaction effect had significant influence on K removal by weeds at 15, 30 and 45 DAS. At 15 DAS, the highest K removal by weeds was noticed in n_1w_6 (67.65 kg ha^{-1}), which was found to be significantly superior to others. At 30 DAS, the highest K removal by weeds was indicated by n_1w_6 (72.38 kg ha^{-1}) and it was on par with n_2w_2 (62.13 kg ha^{-1}). At 45 DAS, the highest K removal by weeds was indicated by n_2w_2 (48.99 kg ha^{-1}) and it was on par with n_1w_2 (45.80 kg ha^{-1})

Table 34a. Effect of nitrogen management and weed management practices on K removal by weeds, kg ha^{-1}

Treatments	K removal by weeds		
	15 DAS	30 DAS	45 DAS
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	27.70	27.48	17.25
n_2 -100% N as urea as per KAU POP	20.64	25.03	20.16
SEm (±)	0.99	1.82	1.61
CD (0.05)	3.088	NS	NS
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	12.52	10.12	18.36
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	3.97	55.40	47.39
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	20.29	20.34	5.61
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	6.51	15.62	9.15
w_5 - HW at 15 and 30 DAS	48.51	3.00	2.95
w_6 - Weedy check	53.23	53.05	28.77
SEm (±)	1.72	3.15	2.78
CD (0.05)	5.35	9.790	8.651

Table 34b. Interaction effect of nitrogen management and weed management practices on K removal by weeds, kg ha^{-1}

Interactions	K removal by weeds		
	15 DAS	30 DAS	45 DAS
NxW interaction			
n_1w_1	21.04	9.58	3.90
n_1w_2	4.86	48.66	45.80
n_1w_3	16.14	18.63	7.29
n_1w_4	5.48	12.89	14.43
n_1w_5	51.02	2.73	2.07
n_1w_6	67.65	72.38	30.02
n_2w_1	4.00	10.65	32.83
n_2w_2	3.07	62.13	48.99
n_2w_3	24.43	22.06	3.93
n_2w_4	7.55	18.35	3.87
n_2w_5	46.01	3.27	3.82
n_2w_6	38.81	33.73	27.53
SEm (±)	2.43	4.45	3.93
CD(0.05)	7.565	13.845	12.24

4.6.7 Available Soil Nitrogen

The influence of nitrogen management and weed management practices on available soil N, kg ha^{-1} is presented in Tables 35a and 35b.

Before the commencement of the experiment, the status of nitrogen availability was low (204.72 kg ha^{-1}). The available soil nitrogen of post-harvest soil was not influenced by both nitrogen management and weed management practices.

N x W interaction effect was also found to be not significant.

4.6.8 Available Soil Phosphorus

The results of effect of nitrogen management and weed management practices on available soil P, kg ha^{-1} is shown in Tables 35a and 35b.

Before the commencement of the experiment, the status of phosphorus availability was 29.21 kg ha^{-1}. The available soil phosphorus of post-harvest soil was not influenced by nitrogen management practices but influenced by weed management practices. The highest available post- harvest soil P was recorded in w_5 (23.02 kg ha^{-1}) which was on par with w_3 (22.29 kg ha^{-1}), w_1 (21.35 kg ha^{-1}), and w_6 (20.35 kg ha^{-1}).

N x W interaction effect was also found to be not significant.

4.6.9 Available Soil Potassium

The results of effect of nitrogen management and weed management practices on available soil K, kg ha^{-1} is shown in Tables 35a and 35b.

Before the commencement of the experiment, the status of potassium availability was 198.26 kg ha^{-1}. Available soil K of post-harvest soil was markedly influenced by both nitrogen management and weed management practices. Nitrogen management, n_1 resulted in higher post-harvest soil K (171.63 kg ha^{-1}) compared to n_2 (159.72 kg ha^{-1}). Within the tactics for weed management, the highest available post-harvest soil K was recorded in w_5 (200.08 kg ha^{-1}) which was found to be significantly superior to others.

N x W interaction effect was found to be not significant.

Table 35a. Effect of nitrogen management and weed management practices on post-harvest nutrient status of soil, kg ha^{-1}

Treatments	Post-harvest soil nutrient status		
	Available N	Available P	Available K
Nitrogen management (N)			
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	260.86	20.82	171.63
n_2 -100% N as urea as per KAU POP	267.60	19.88	159.72
SEm (±)	18.94	0.76	2.93
CD (0.05)	NS	NS	9.12
Weed management (W)			
w_1 -PE Pendimethalin at 1 kg ha^{-1}	263.98	21.35	184.01
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	238.33	18.72	125.66
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	248.91	22.29	181.38
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	301.05	16.37	127.31
w_5 - HW at 15 and 30 DAS	238.33	23.02	200.08
w_6 - Weedy check	294.79	20.35	175.62
SEm (±)	32.80	1.32	5.08
CD (0.05)	NS	4.113	15.796

Table 35b. Interaction effect of nitrogen management and weed management practices on post-harvest nutrient status of soil, kg ha^{-1}

Interactions	Post-harvest soil nutrient status		
	Available N	Available P	Available K
NxW interaction			
n_1w_1	239.45	23.55	178.22
n_1w_2	238.33	37.16	129.25
n_1w_3	272.04	16.82	188.90
n_1w_4	344.96	7.98	144.15
n_1w_5	225.79	2.73	209.25
n_1w_6	244.61	31.37	180.02
n_2w_1	288.51	27.24	189.79
n_2w_2	238.34	24.87	122.07
n_2w_3	225.79	16.04	173.87
n_2w_4	257.15	19.88	110.48
n_2w_5	250.88	4.95	190.90
n_2w_6	344.97	25.16	171.22
SEm (±)	46.39	1.87	7.18
CD(0.05)	NS	NS	NS

4.7 ECONOMIC ANALYSIS

The results of the economic analysis of the effect of nitrogen management and weed management in okra are presented in Tables 36a and 36b.

4.7.1 Net Income

Among the nitrogen management practices, n_1 was more remunerative since it recorded a net income of ₹ 35,036 ha^{-1} compared to n_2 (₹21954 ha^{-1}).

The highest net income was observed in w_5 (₹ 52,588 ha^{-1}), which was on par with w_3 (₹ 42,516 ha^{-1}) and w_1 (₹ 36,928 ha^{-1}). The net income recorded was least in w_2 (₹ 9,336 ha^{-1}).

Among the treatment combinations, the highest net income was noted in n_1w_5 (₹ 66,070 ha^{-1}), which was followed by n_1w_3 (₹ 56,267 ha^{-1}).

4.7.2 B : C Ratio

B: C ratio also followed the same trend as net income. The highest B:C ratio was observed in nitrogen management practice, n_1 (1.34) compared to n_2 (0.97).

The highest B:C ratio was noted in w_3 (1.75), which was on par with w_5 (1.65) and w_1 (1.52) and the lower most was noted in w_2 (0.60).

Among the treatment combinations, the highest B:C ratio was observed in n_1w_3 (2.16) which was followed by n_1w_5 (1.96) and the lowest was noticed in n_2w_2 (0.59).

From the results it could be concluded that, application of 50 per cent recommended dose of nitrogen as urea in soil + Nano N as 0.2 per cent nanourea spray at 20 DAS and 40 DAS (n_1) along with two hand weedings at 15 DAS and 30 DAS (w_5) was very effective in reducing the weed density and weed biomass and resulted in higher WCE, higher yield and NPK uptake. However pre-emergence Pendimethalin at 1 kg ha^{-1}followed by hand weeding at 30 DAS (w_3) resulted in higher B:C ratio. Considering the economics, n_1 with pre-emergence pendimethalin at 1 kg ha^{-1} *fb* hand weeding at 30 DAS (w_3) could be adjudged as the most effective nitrogen based integrated weed management practice in okra.

Table 36a. Effect of nitrogen management and weed management practices on net income (₹ ha^{-1}) and B:C ratio

Treatments	Net income (₹ ha^{-1})	B:C Ratio
Nitrogen management (N)		
n_1 -50% RDN in soil + 0.2% nano urea at 20 and 40 DAS	35036	1.34
n_2 -100% N as urea as per KAU POP	21954	0.97
SEm (±)	3956	0.13
CD (0.05)	11603.33	0.39
Weed management (W)		
w_1 -PE Pendimethalin at 1 kg ha^{-1}	36928	1.52
w_2 -PE Oxyfluorfen at 0.15 kg ha^{-1}	9336	0.60
w_3 - PE Pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS	42516	1.75
w_4 - PE Oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS	16323	0.79
w_5 - HW at 15 and 30 DAS	52588	1.65
w_6 - Weedy check	13279	0.74
SEm (±)	6852	0.23
CD (0.05)	20097	0.67

Table 36b. Interaction effect of nitrogen management and weed management practices on net income (₹ ha^{-1}) and B:C ratio

Interactions	Net income(₹ ha^{-1})	B:C Ratio
NxW interaction		
n_1w_1	45832	1.83
n_1w_2	10014	0.61
n_1w_3	56267	2.16
n_1w_4	17546	0.84
n_1w_5	66070	1.96
n_1w_6	14489	0.76
n_2w_1	28023	1.20
n_2w_2	8659	0.59
n_2w_3	28765	1.24
n_2w_4	15099	0.74
n_2w_5	39106	1.33
n_2w_6	12069	0.72
SEm (±)	9690	0.32
CD (0.05)	NS	NS

DISCUSSION

5. DISCUSSION

Weeds have a greater ability to absorb nutrients at a faster rate and in relatively larger quantities compared to crop plants. Effectively managing crop fertilization is a crucial component in integrated weed control systems. Using chemical methods for weed control can be an economically viable option to manage the diverse weed population. A critical analysis of the experimental results obtained from the studies conducted and their significance in devising effective weed management strategies are discussed hereunder.

5.1 GROWTH AND GROWTH ATTRIBUTES OF OKRA UNDER THE INFLUENCE OF NITROGEN MANAGEMENT AND WEED MANAGEMENT

The results of the study demonstrated the impact of nitrogen management, weed management, and their interaction on the plant height, number of branches per plant, number of leaves per plant, LAI and DMP of okra. Results indicated that nitrogen management significantly impacted all the growth attributes, with 50% recommended dose of nitrogen (RDN) in soil + 0.2% nano urea at 20 and 40 DAS (n_1) resulting in taller plants with more number of branches and leaves compared to 100 per cent N as urea as per KAU POP (n_2). Moreover, significant increase in leaf area index and dry matter production in okra was observed in n_1. Placement of urea in soil might have led to excessive weed competition that can reduce nutrient uptake and utilization by crops, leading to comparatively shorter plants. Weeds not only reduce the amount of N available to crops, but also the growth of many weed species is enhanced by higher soil N levels (Jahali *et al.,* 2012). Foliar application of nutrients is recognized for its highly efficient and rapid absorption by plants, resulting in almost complete utilization of the applied nutrients. It helps to minimize leaching losses and nutrient fixation, contributing to better nutrient management. Higher nitrogen availability can enhance the competitive ability of crops against weeds, resulting in taller plants. Additionally, foliar application aids in regulating the uptake of nutrients by plants, ensuring they receive the required amounts for optimal growth and development. Lower size of nano urea enables the absorption of numerous ions due to their high surface area and subsequent slow release in a timely manner as required by the crop (Helaly *et al.,* 2021). Lekshmi *et al.* (2022) reported that 50 per cent foliar application with Nano N in okra resulted in tallest plants with highest number of leaves and branches.

Among the weed management practices, hand weeding (HW) at 15 and 30 DAS (w_5) produced taller plants with more number of branches and leaves, followed by pre-emergence application of pendimethalin at 1 kg ha^{-1} followed by one hand weeding at 30 DAS (w_3). The oxyfluorfen at 0.15 kg ha^{-1} (w_2) and weedy check plots had lowest of all growth attributes. The higher values of growth parameters recorded from w_5 and w_3 suggested the effectiveness of these weed control measures. As the weed pressure in okra diminished due to effective weed management in these treatments, the availability of space, nutrients and sunlight for okra plants enhanced, which resulted in accelerated growth. Sah *et al.* (2018) observed plant height and number of leaves at par with hand weeding twice at 20 and 40 DAS, when pendimethalin at 1 kg ha^{-1} was applied in okra. Similarly, Patel *et al.* (2017) reported the effectiveness of pendimethalin 1 kg ha^{-1} in okra with taller plants which was at par with hand weeding done at 20 and 40 DAS.

However, application of oxyfluorfen showed a marked reduction in growth attributes exhibiting its toxic effect on okra. The delayed germination and toxicity symptoms observed in the coleoptile, such as a crinkled appearance and retarded growth served as clear indicators of phytotoxicity (Plate 9). The symptoms of delayed growth and retardation persisted for a period of three weeks following emergence. This could be the reason for the poor performance of okra sprayed with oxyfluorfen. In a study conducted by Langaro *et al*. (2017), it was found that plants exposed to oxyfluorfen exhibited greater phytotoxicity and reduction in height compared to those treated with pendimethalin.

The interaction between nitrogen and weed management showed significant variation in plant height and number of leaves at 30 and 60 DAS, respectively, while it was not significant with respect to number of branches. Nitrogen management with foliar nanourea application and HW twice produced taller plants with more number of leaves at 30 and 60 DAS, respectively. This could be attributed to reduced competition from weeds resulting from the application of nutrients directly to foliage, as well as improved nitrogen availability as evident from lower weed dry weight in n_2 at 30 and 45 DAS (Table 16a). Nitrogen is an essential nutrient for plant growth and method of

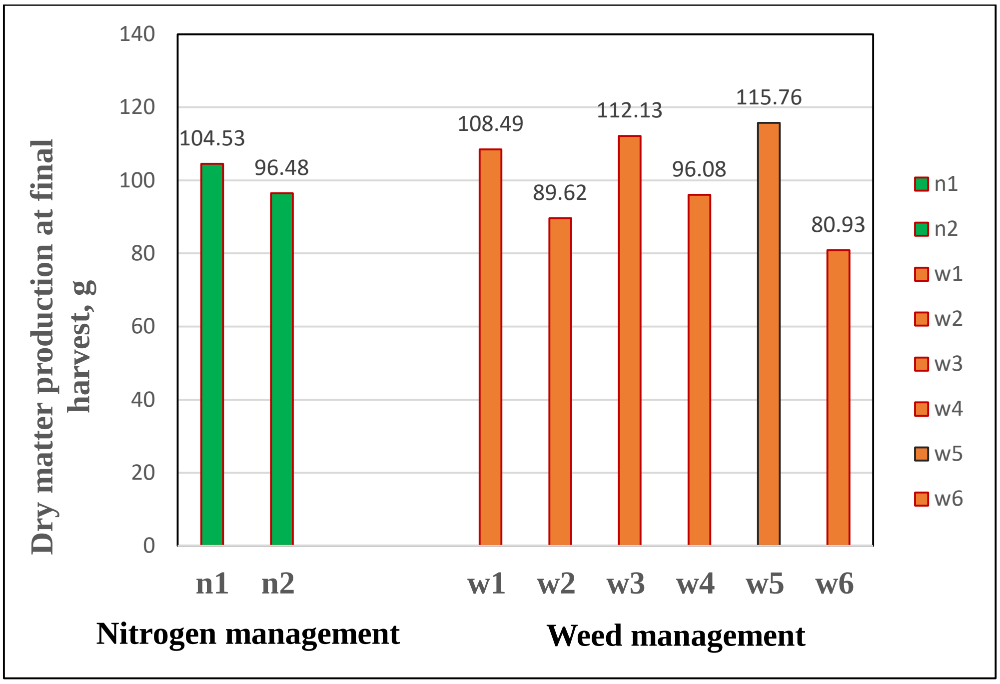

Fig 3. Effect of nitrogen management and weed management practices on DMP at final harvest, g

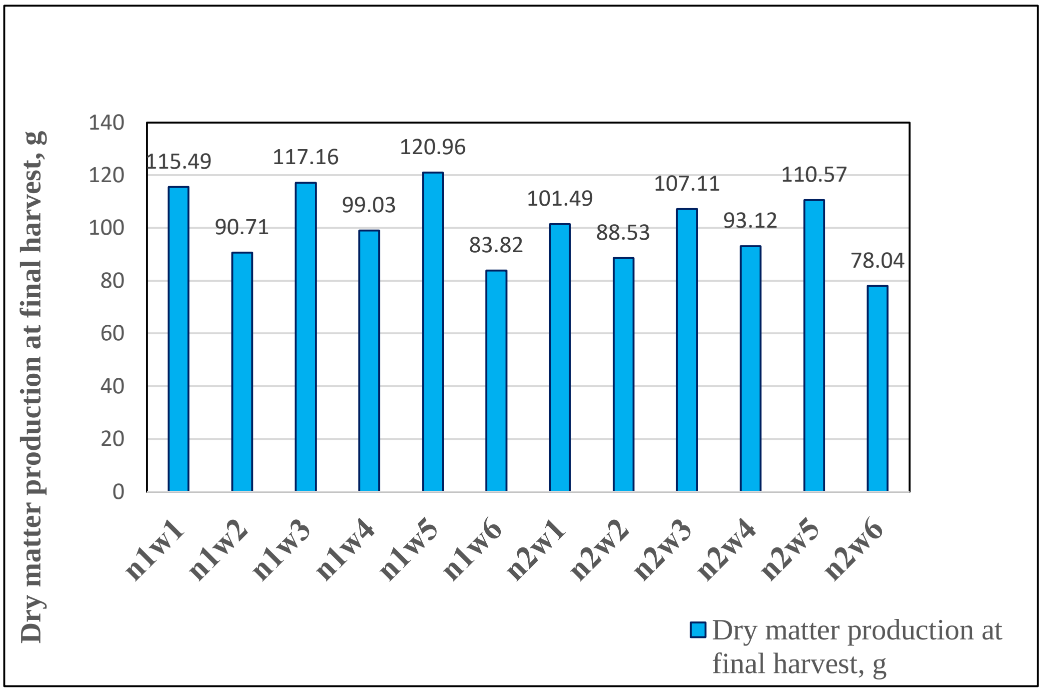

Fig 4. Interaction effect of nitrogen management and weed management practices on DMP at final harvest, g

nitrogen application can significantly affect growth attributes. Appropriate nitrogen availability to okra by way of foliar application through nano urea at 20 and 40 DAS have promoted vigorous growth resulting in taller plants. Additionally, foliar spray can shorten the delay between application and plant uptake during the phase of quick growth (Banotra et al., 2017).

Hand weeding at 15 DAS and 30 DAS demonstrated superior results in terms of leaf area index and dry matter production. This was followed closely by the combined use of pendimethalin as pre-emergence along with hand weeding. Imoloame and Usman (2018) reported that pendimethalin at 1.0 kg ha^{-1} plus one supplementary hoe weeding gave rise to crops with significantly high leaf area and was comparable with two hoe weedings. Nitrogen management with foliar nanourea application and HW twice produced higher LAI at 20 and 40 DAS, followed by nanourea with pendimethalin *fb* HW, indicating that weed free condition along with foliar spray of nano urea accelerated the leaf area development.

The taller plants were better suited to utilize light and space, which might have resulted in increased number of leaves at 60 DAS. Weeds exert competitive pressure on crops and in several instances have shown higher efficiency of nitrogen uptake. However, pre-emergence pendimethalin application curtailed the growth of weeds during the initial period and the plants had better opportunity to grow. Plants with higher leaf area index will intercept light efficiently and thus will photosynthesize more. This leads to better accumulation and translocation of photosynthates and ultimately higher dry matter production at harvest. Rehman *et al.* (2013) reported a strong correlation between growth attributes and dry matter production. The results are in line with Gomaa *et al.* (2016) who observed higher dry matter production in sorghum when chemical weed control methods were used along with 50 per cent nano N fertilization.

5.2 YIELD AND YIELD ATTRIBUTES OF OKRA AS INFLUENCED BY NITROGEN MANAGEMENT AND WEED MANAGEMENT

Results showed that nitrogen management significantly modified yield and all the yield attributes, with 50 per cent RDN in soil + 0.2 per cent nano urea at 20 and 40 DAS (n_1) resulting in higher number of fruits per plant, fruit length, fruit weight, fruit yield per plant, haulm yield per plant and harvest index of okra compared to 100 per cent N as urea as per KAU POP (n_2). The nitrogen application method, where only half the required amount is applied to the soil potentially reduced the weed competition and its impact on crop growth (Table 16a) and prevented weeds from taking up excessive nitrogen, which could lead to increased competition with the crop. By reducing the availability of nitrogen to weeds, the crop had a better chance to thrive with reduced weed competition. Nano fertilizers (NFs) also have special physio-chemical characteristics that make them superior to conventional chemical fertilizers. NFs contain more nutrients and release them slowly as needed by the crop without having any negative effects because they have a larger surface area than typical chemical fertilizers (Siddiqi and Husen, 2017). When applied as a basal spray or foliar spray, NFs can infiltrate plant systems due to their small particle size (100 nm) (Seleiman *et al.*, 2021). In comparison to typical bulky chemical fertilizers, NFs have a higher capacity for absorption and retention due to their ultra-small size and high surface area to volume ratio (Hussain *et al.*, 2022). The findings are consistent with those published by Lekshmi *et al.* (2022), who showed a significant improvement in yield and yield characteristics with nano nitrogen application at 50% compared to conventional fertilizer.

Yield and yield components differed significantly among the weed management practices. HW at 15 and 30 DAS (w_5) produced more number of fruits per plant, fruit length, fruit weight, fruit yield per plant, haulm yield per plant, fruit yield per hectare, haulm yield per hectare and harvest index of okra. It was followed by PE pendimethalin at 1 kg ha^{-1} *fb* HW at 30 DAS (w_3) with respect to number of fruits per plant, fruit yield per plant and haulm yield per plant. The reason behind this could be attributed to the use of pre-emergent herbicides in keeping the crop weed-free during the early stages of growth. The practice of combining herbicides with one hand weeding enhanced the efficiency in managing weeds (Table 17a). These results were in conformity with findings of Baraiya *et al.* (2017) who reported that HW twice at 30 and 60 DAS recorded significantly higher number of fruits per plant, length of fruit and fruit girth which was on par with pendimethalin @ 1.00 kg ha^{-1} as PE and pendimethalin @ 1.00 kg ha^{-1} as PE + 1 HW at 30 DAS.

Lesser number of fruits per plant, fruit length, fruit weight and haulm yield per

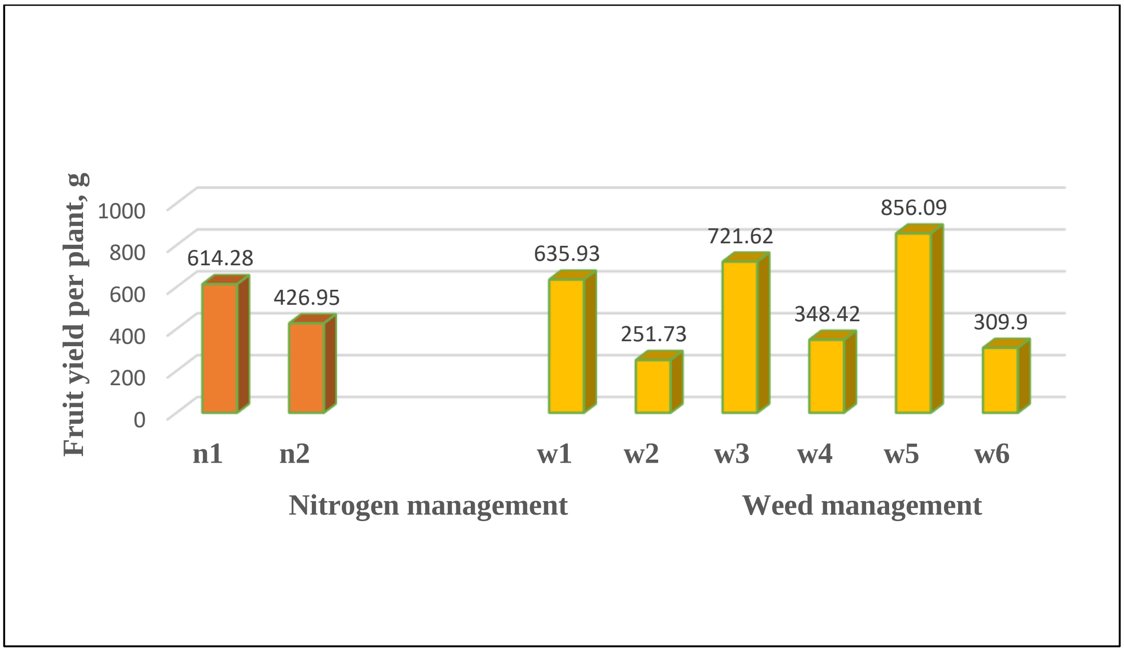

Fig 5. Effect of nitrogen management and weed management practices on fruit yield per plant, g

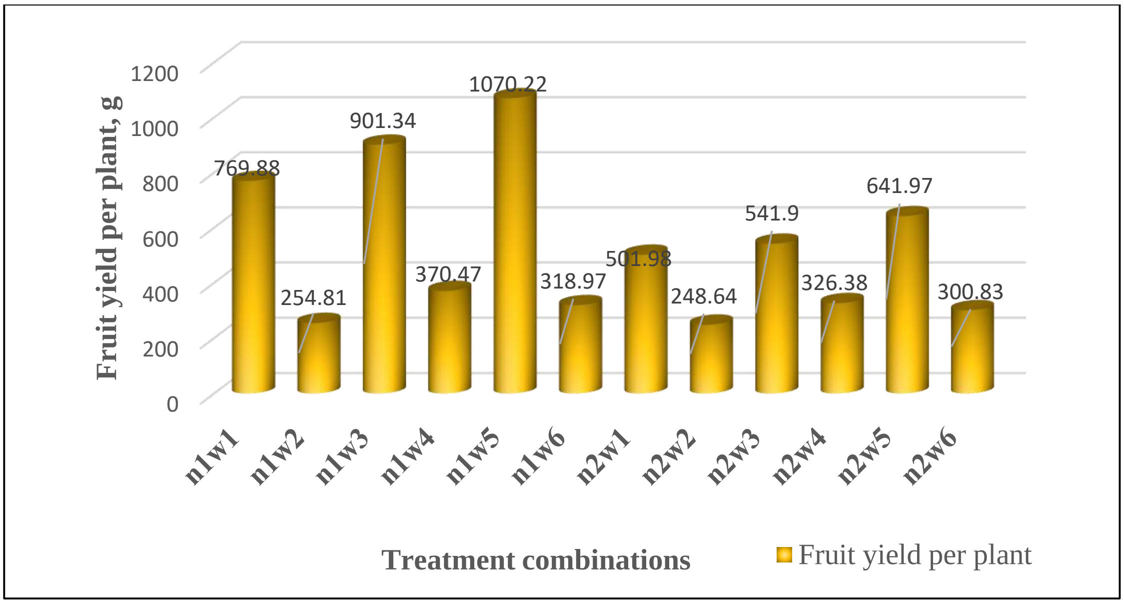

Fig 6. Interaction effect of nitrogen management and weed management practices on fruit yield per plant, g

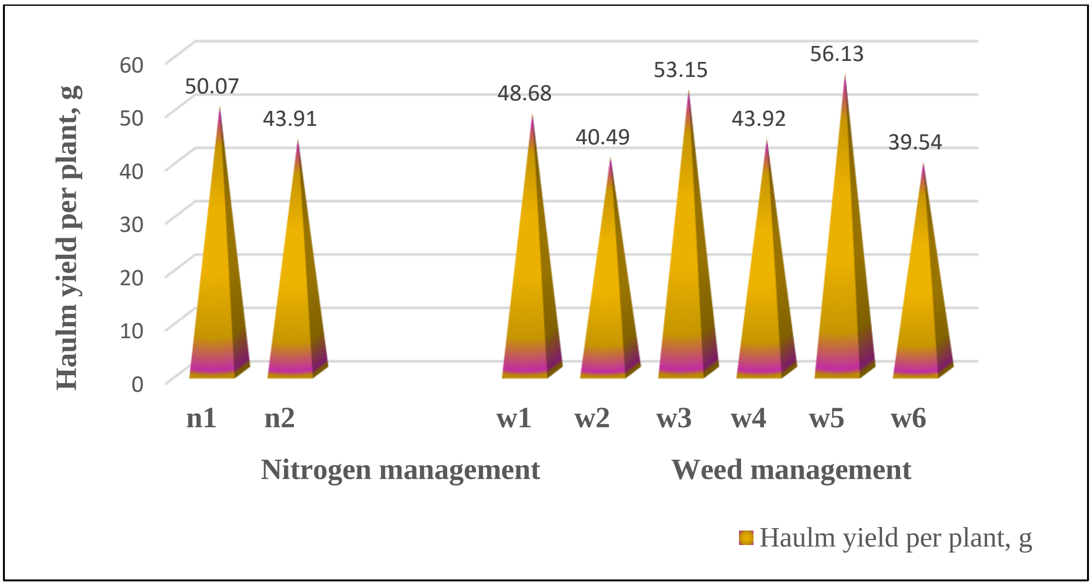

Fig 7. Effect of nitrogen management and weed management practices on haulm yield per plant, g

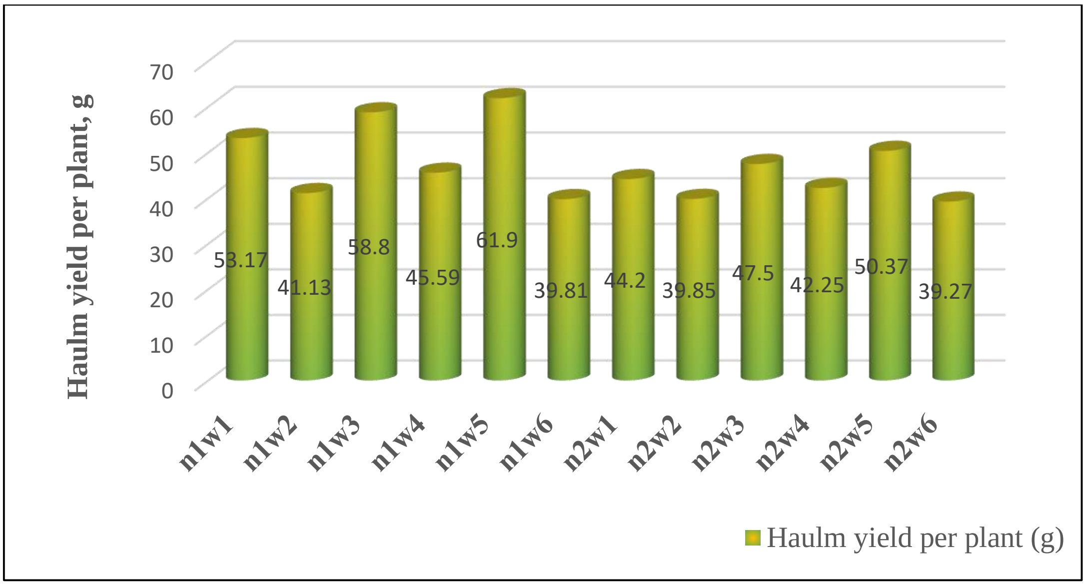

Fig 8. Interaction effect of nitrogen management and weed management practices on haulm yield per plant, g

Plate 4. Performance of the treatment n_1w_5 at different growth stages

Plate 5. Performance of the treatment n_1w_3 at different growth stages

Plate 6. Toxic effect of oxyfluorfen on growth

plant were recorded by weedy check (w_6) which was on par with PE oxyfluorfen at 0.15 kg ha^{-1} (w_2). The inefficiency of oxyfluorfen and lower yield in oxyfluorfen treated plots was due to its toxicity effects on okra which was evident from the crinkled coleoptiles which prevailed up to three weeks after emergence which further retarded its growth and yield attributes. Low mobility of oxyfluorfen in clay loam (Tandon, 2018) soils might have led to higher persistence at the soil surface leading to seedling toxicity. Jursik *et al.* (2011) reported phytotoxicity of oxyfluorfen in sunflower at 2 to 4 leaf stage. Baraiya *et al.* (2017) reported minimum number of fruits per plant, length of fruit and fruit girth in weedy check which was on par with oxyfluorfen @ 0.25 kg ha^{-1} as PE and oxyfluorfen @ 0.25 kg ha^{-1} as PE + 1 HW at 30 DAS in okra. Narayan *et al.* (2020) also found that two to three hand weeding produced maximum average fruit weight and fruit yield which was on par with PE pendimethalin application @ 6ml L^{-1} and PE pendimethalin @ 6ml L^{-1} + one hand weeding in okra.

Interactions between nitrogen management and weed management practices were found significant with respect to yield and yield attributes. Application of 50% RDN in soil + 0.2% nano urea at 20 and 40 DAS along with HW at 15 and 30 DAS (n_1w_5) resulted in higher number of fruits per plant, fruit yield per plant, haulm yield per plant and harvest index of okra. This might be due to the fact that herbicidal application had killed the weeds in crop while the N fertilization had provided sufficient nutritional requirements for the plants to rapidly grow and hence promoted its yield. These results are in similar line with findings of Kanjana (2020) who reported that, compared to conventional fertilizers, commercially available nano urea was better in increasing growth and yield parameters. HW at 15 and 30 DAS, as well as PE pendimethalin at 1 kg ha^{-1} fb HW at 30 DAS, all demonstrated better growth and development throughout the crop growth period due to excellent weed control, less competition from weeds during the critical growth stage of the crop, and ultimately produced higher yields than all other treatments. Similar observations were made by Dash *et al.* (2020). The extent of yield reduction in okra due to weed infestation as estimated from weedy check was 69.88 (n_1w_6) and 70.36 (n_2w_6) with an average loss of 70.12 per cent. Lowest number of fruits per plant, fruit yield per plant and haulm yield per plant were recorded by 100 per cent N as urea as per KAU POP along with weedy check which was on par with PE oxyfluorfen at 0.15 kg ha^{-1} along with 50 % RDN in soil + 0.2% nano urea at 20 and 40 DAS or 100 per cent N as urea as per KAU POP.

5.3 WEED FLORA AND WEED CONTROL PARAMETERS AS INFLUENCED BY NITROGEN MANAGEMENT AND WEED MANAGEMENT

Results of predominant species of weeds observed in the experimental field showed the dominance of grasses as major weed flora. However, more diversity was observed in broad leaf weeds. *Trianthema portulacastrum* L., *Cleome rutidosperma* L., *Alternanthera sessilis* L., *Synedrella nodiflora* (L.) Gaertn, *Phyllanthus niruri* L., *Euphorbia geniculata* L., *Boerhaavia diffusa* L., and *Tridax procumbens* were the major broaf leaf weeds observed. Diversity of sedges was low and *Cyperus rotundus* L. was the only sedge observed in the experimental field. Nandwani (2013) also reported the increased diversity of broadleaved weeds in okra. Daramola *et al*. (2020) also observed *Cyperus rotundus* as the sole sedge species with moderate level of infestation (30-59 per cent) throughout the crop growth period of okra.

Nitrogen management practices significantly impacted the density of grass weeds at 45 DAS with nanourea application having the lower most grass weed density at 45 DAS. However, nitrogen management did not have significant impact on grass weed density at 15 and 30 DAS. Patel *et al*. (2022) reported higher density of monocot weeds in plots sprayed with oxyfluorfen at 0.24 kg ha^{-1} at 40 DAS and harvesting stages of okra. Weed management practices significantly altered grass weed density at 15 and 45 DAS. The data on total weed density of sedges and broad leaf weeds showed that it was not significantly affected by nitrogen management practices. However, weed management practices had significant influence on density of broad leaf weeds at all growth stages. This could be due to the fact that nutsedge being the major sedge propagated by underground tubers was unaffected by the pre-emergence herbicides applied in the study. However, at 45 DAS there was a substantial decrease in the number of broadleaved weeds in the plots treated with pendimethalin fb HW at 30 DAS. This could be due to the increase in the density of sedges in the field at 45 DAS compared to 15 and 30 DAS.

Weed dry weight is an efficient index for measuring the crop-weed

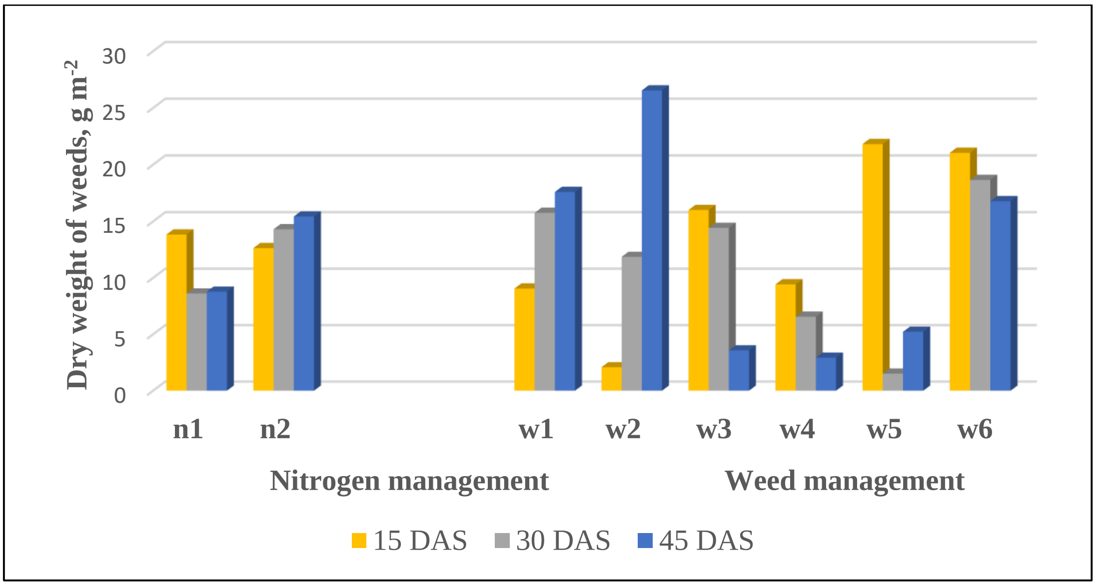

Fig 9. Effect of nitrogen management and weed management practices on dry weight of weeds, g m^{-2}

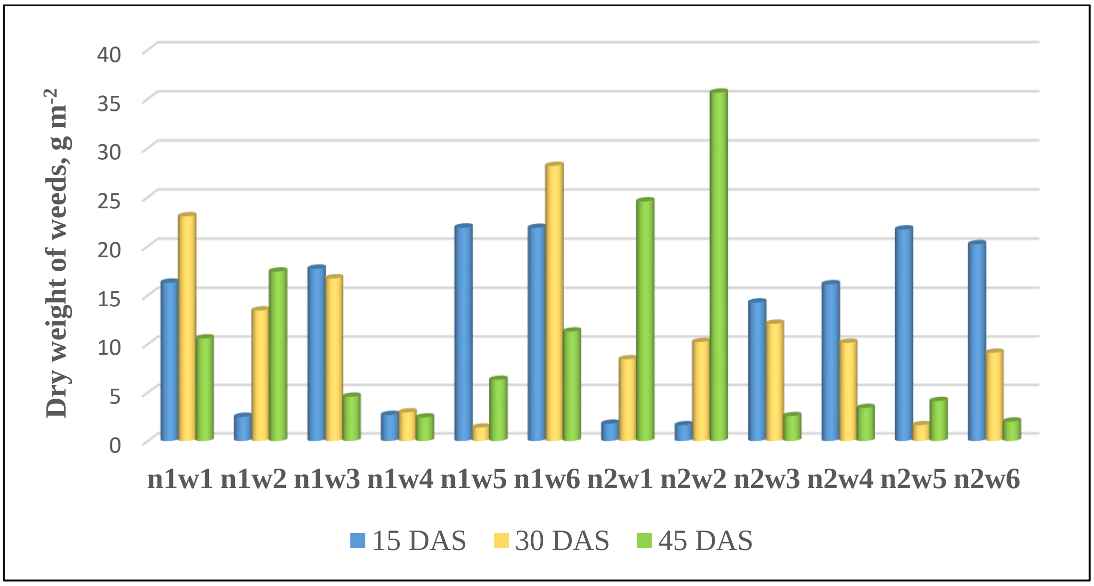

Fig 10. Interaction effect of nitrogen management and weed management practices on dry weight of weeds, g m^{-2}

competition, compared to weed density (Channappagoudar *et al*., 2013). Nitrogen management practices significantly impacted the weed dry weight at 30 DAS and 45 DAS. But at 15 DAS, higher weed dry weights were recorded in both the treatments of nitrogen management. The non-significance between the treatments might be due to the application of the same source of nitrogen initially in both the treatments in the form of urea which attributed to equal nitrogen availability for both crops and weeds. Spraying with 0.2 per cent nano urea at 20 and 40 DAS (n_1) was found efficient at 30 and 45 DAS due to 39.79 and 43.16 per cent less weed dry weight, respectively compared to soil application of entire dose of nitrogen as urea (n_2)., nano urea delivers nitrogen directly to the foliage of the crop compared to conventional urea triggering alternate nutrient pathways and increase the nitrogen use efficiency without any adverse environmental impact (Kumar *et al*., 2021).

All the weed management practices significantly altered the weed dry weight at all stages of crop growth *viz.* 15, 30 and 45 DAS. Among the six different treatments, oxyfluorfen at 0.15 kg ha^{-1} fb HW at 30 DAS (w_4) recorded the lower dry weight of weeds, 2.92 g at 45 DAS and was 46.06 and 83.40 per cent more efficient than hand weeding twice at 15 and 30 DAS. The application of pendimethalin at 1 kg ha^{-1} (w_1) and oxyfluorfen at 0.15 kg ha^{-1} (w_2) alone was ineffective in managing the weeds at 30 and 45 DAS, whereas both the herbicides followed by hand weeding at 30 DAS suppressed weed growth significantly. This could be due to the extended period of weed management ensured by hand weeding treatment. Smith *et al.* (2009) reported the efficacy of pendimethalin based methods of weed management as effective for obtaining season-long weed management. Pre-emergence herbicides keeps the weed population below the economic threshold during the early crop growth stages whereas a follow up hand weeding gives effective weed management at later stages of crop (Shivalingappa *et al*., 2014). Integration of herbicides with hand weeding is a less laborious, cost effective and promising alternative to hand weeding twice at 3 and 6 WAS or 4 and 8 WAS (Imoloame and Usman, 2018). In okra, Sah *et al*. (2018) obtained lower weed dry weight in plots treated with pendimethalin at 1.5 kg ha^{-1} followed by hand weeding at 40 DAS compared to hand weeding twice. At 30 DAS, lowest weed dry weight was obtained from hand weeded plots irrespective of the source of nitrogen used.

Nitrogen management practices exerted significant effect on the weed control efficiency at 30 and 45 DAS. Lower weed control efficiency of n_1 at 15 DAS (48 per cent) was increased to 60.92 per cent at 30 DAS. Highest weed control efficiency of 63.76 per cent at 45 DAS was obtained with n_1 and it was 22.49 per cent more efficient than n_2. Soil applied urea had enhanced weed growth due to equal availability of nitrogen in the crop and weed rhizospheres and this would have resulted in the reduction of weed control efficiency from 15 to 45 DAS.

Weed management practices played a significant role in determining the weed control efficiencies at 15, 30 and 45 DAS. At early stages of okra (15 DAS), oxyfluorfen at 0.15 kg ha^{-1} (w_2) both alone and in combination with hand weeding at 30 DAS (w_4) effectively managed the weeds thus possessing a higher weed control efficiency index of 94.08 and 79.58 per cent, respectively. At 30 DAS, hand weeding twice at 15 and 30 DAS (w_5) exhibited the highest weed control efficiency of 94.82 per cent which was 28.84 and 43.12 per cent more efficient in weed management than the pre-emergence pendimethalin at 1 kg ha^{-1} alone and oxyfluorfen at 0.15 kg ha^{-1} alone, respectively and was also 36.98 and 29.76 per cent more effective compared to the combination of hand weeding with pre-emergence pendimethalin at 1 kg ha^{-1} and oxyfluorfen at 0.15 kg ha$^{-1.}$ At 45 DAS, pre-emergence pendimethalin at 1 kg ha^{-1} fb HW at 30 DAS recorded the highest weed control efficiency of 89.35 per cent and was 35.72 per cent more efficient than pre-emergence pendimethalin solely at the same dose. Higher efficacy of pre-emergence pendimethalin 30 EC at 3 L ha^{-1} followed by hand weeding at 45 DAS compared to sole pre-emergence pendimethalin application was reported by Moolchand *et al.* (2010). The period of weed management could be extended to later stages of the crop by providing hand weeding or by the post-emergence application of herbicides. Among the management practices tested, weedy check recorded the least weed control efficiency at all stages of okra crop. This could be attributed to the non-adoption of any weed management practices in the weedy check that aided in the uninterrupted growth of monocot, dicot and sedge weeds.

The data indicated a substantial impact of nitrogen management practices on weed control efficiency. At 30 and 45 DAS, topdressing by nanourea application (n_1) demonstrated superior weed control compared to n_2. This could potentially be attributed to the application of nano urea to the foliage which would selectively favour the crop resulting in broader, healthy leaves which suppressed the growth of grasses; whereas soil application of urea would have favoured both the crop and weed equally in obtaining the nutrient requirement of urea in soil, which might have stimulated weed growth.

Nitrogen and weed management practices significantly affected the weed control efficiency at 15, 30 and 45 DAS, upon interaction. At 15 DAS, pre-emergence application of oxyfluorfen at 0.15 kg ha^{-1} with urea application, pendimethalin at 1 kg ha^{-1} with urea application and pendimethalin 1 kg ha^{-1} fb HW at 30 DAS with nano urea application exhibited higher weed control efficiencies of 98.96, 97.96 and 93.95 per cent, respectively. This could be ascribed to the efficacy of pendimethalin and oxyfluorfen herbicides in inhibiting the weed seed germination and emergence at the early stages of the crop. At 30 DAS, after hand weeding at 15 DAS, irrespective of the source of nitrogen, both n_1w_5 and n_2w_5 were equally effective in managing weeds. Compared to the pre-emergence application of herbicides alone, the plots in which herbicides and hand weeding was integrated gave higher weed control efficiencies. Pre-emergence application of oxyfluorfen at 0.15 kg ha^{-1} provided only an initial short period of effective weed management and its efficacy decreased over time (from 15 DAS to 45 DAS) to the tune of 81.11 and 87.68 per cent in plots that received nano urea spray and soil application of urea, respectively. Decrease in the efficiency of oxyfluorfen as pre-emergence spray in okra from 20 DAS to harvest by 71.96 per cent was reported by Baraiya *et al*. (2017). Pendimethalin at 1 kg ha^{-1} fb HW at 30 DAS, irrespective of the source of nitrogen was equally effective with an extended period of weed management having weed control efficiencies of 92.80 and 92.14 per cent, respectively. Pre-emergence pendimethalin at 1 kg ha^{-1} fb HW at 30 DAS was 6.7 and 23.77 per cent more efficient than pre-emergence application of oxyfluorfen at 0.15 kg ha^{-1} fb HW at 30 DAS with nano urea spray and soil application of urea as per KAU POP, respectively. The increased efficiency with nano urea could be related to the unavailability of nitrogen source to the weeds at the later stages of crop growth due to foliar spray of nano urea.

Relative weed density of grasses was significantly modified by nitrogen and weed management practices at 45 DAS. Weed management practices had significant effect on the relative density of broadleaved weeds irrespective of the source of nitrogen applied. However, both nitrogen and weed management practices did not play a significant role on the relative density of sedges. At 45 DAS, the grass population was 59.06 per cent lesser in nano urea treated plots compared to the plots that were given soil application of urea as per KAU POP. Hand weeding twice was found to be the most effective with the lowest sedge density at 45 DAS. Weed management practices had significant influence on the relative biomass of grasses at all stages and broadleaved weeds at 15 and 30 DAS.

Comparing the treatment combinations, n_1w_3, n_1w_4 and n_2w_4 were effective in managing grasses at 45 DAS. Hand weeding twice at 15 and 30 DAS with nano urea spray was completely effective in managing sedges and broadleaved weeds at 45 DAS. Relative weed biomass of grasses was significantly modified by the nitrogen management practices at 15 and 45 DAS where 50 per cent RDN in soil + 0.2 per cent nano urea at 20 and 40 DAS recorded the least relative biomass of grass. The relative biomass of sedges and broadleaved weeds were not significantly affected by the nitrogen management practices at any stage of crop growth. Bajaj and Yadav (2016) reported that in okra, the pre-emergence pendimethalin at 1 kg ha $^{-1}$ fb HW at 30 DAS exhibited a weed control efficiency of 90.34 per cent and was found to be more efficient than sole application of pendimethalin at the same dose and also because that the plants sprayed with oxyfluorfen at 0.25 kg ha^{-1} exhibited phytotoxic symptoms. The decreased efficacy could be due to the dissipation and deactivation of the pre-emergence herbicides in the soil, making the herbicide ineffective after a particular period of weed management (Patel *et al*., 2022).

5.4 PHYSIOLOGICAL PARAMETERS AND FRUIT QUALITY UNDER THE INFLUENCE OF NITROGEN MANAGEMENT AND WEED MANAGEMENT

The chlorophyll content, which serves as the primary component of chloroplasts for photosynthesis, is directly correlated with the rate of photosynthesis. Nitrogen management with nanourea recorded significantly higher chlorophyll content compared to 100% N as urea as per KAU POP (n_2). Increase in nitrogen concentration level had significantly increased the chlorophyll content. According to Purbanjanti *et al* (2019), the total chlorophyll content of okra showed a significant increase of 55 to 138.3 per cent when the compost nitrogen (N) was increased from 50 to 150 kg ha^{-1}. Weed

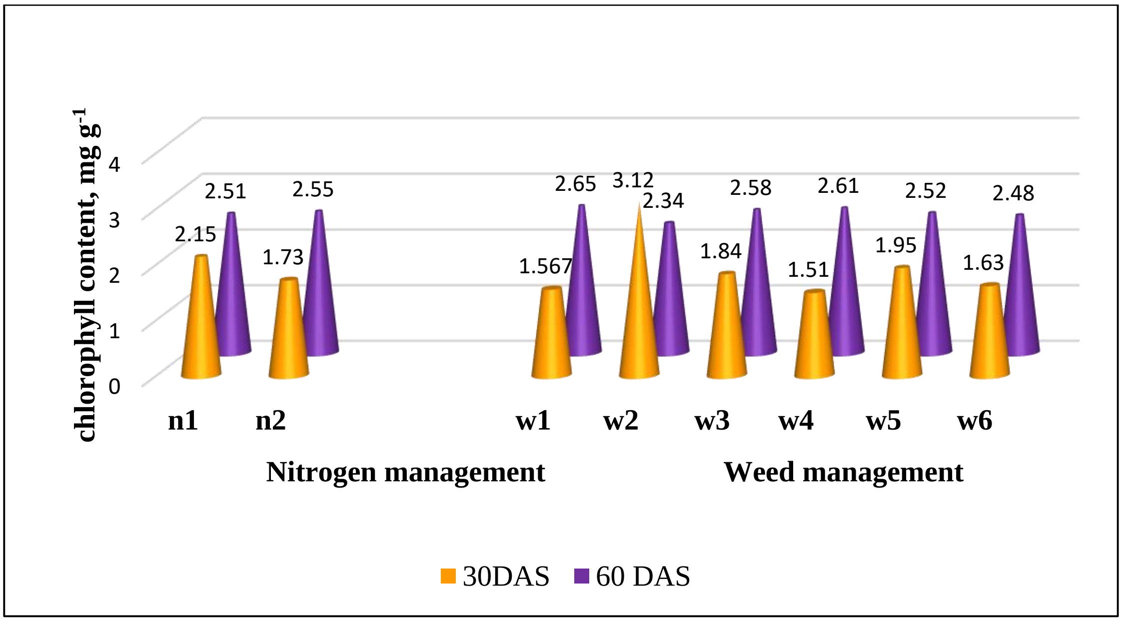

Fig 11. Effect of nitrogen management and weed management practices on total chlorophyll content in okra, mg g^{-1}

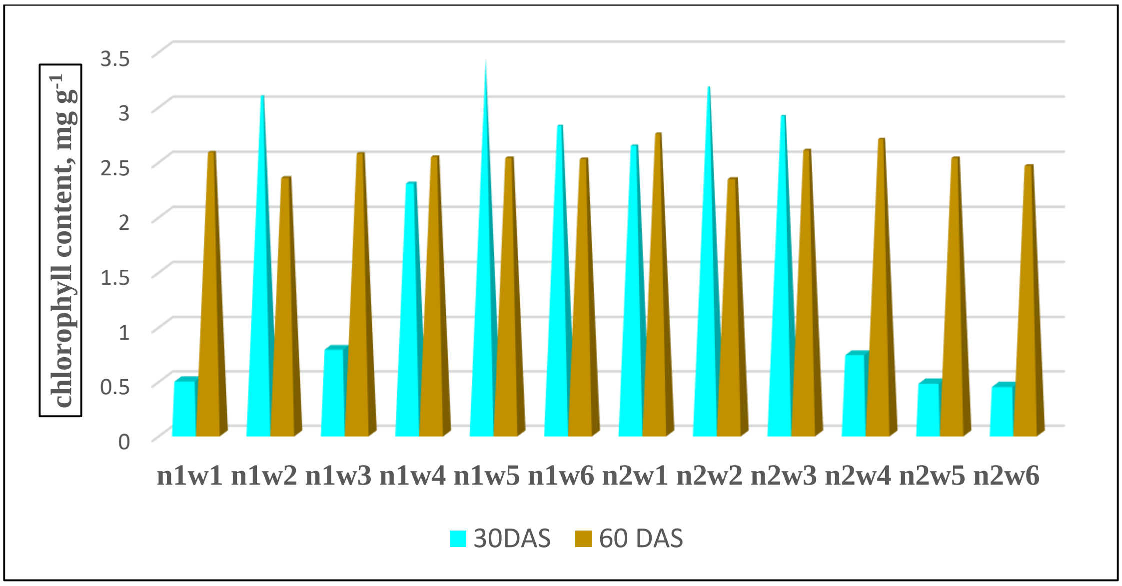

Fig 12. Interaction effect of nitrogen management and weed management practices on total chlorophyll content in okra, mg g^{-1}

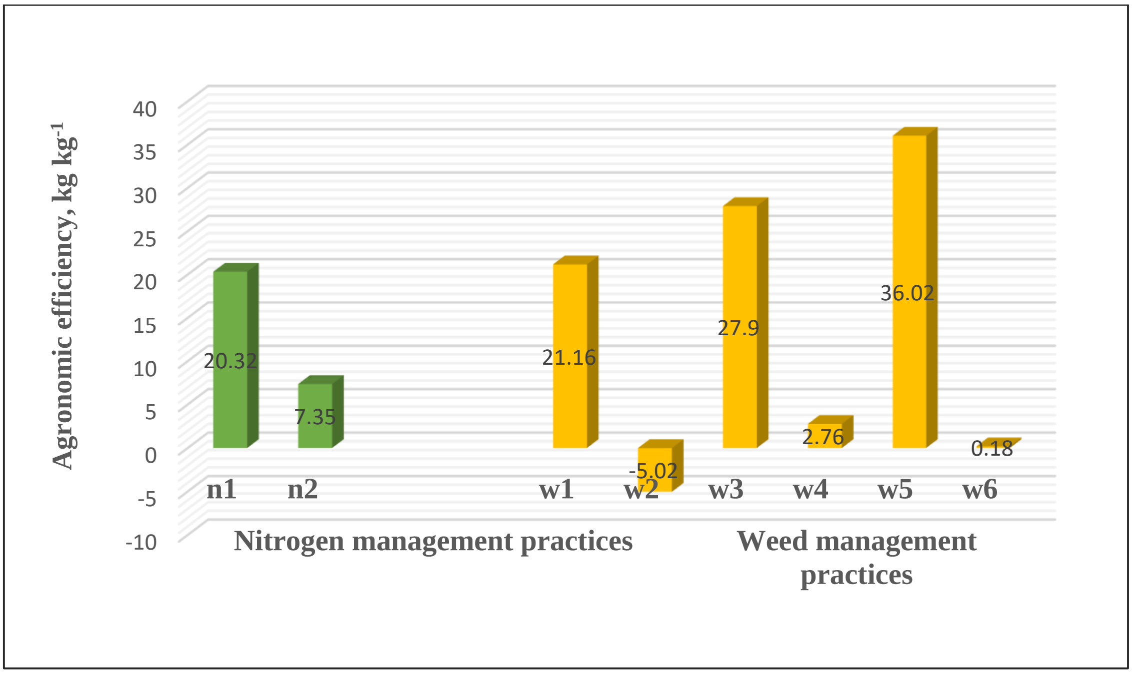

Fig 13. Effect of nitrogen management and weed management practices on agronomic efficiency, kg kg^{-1}

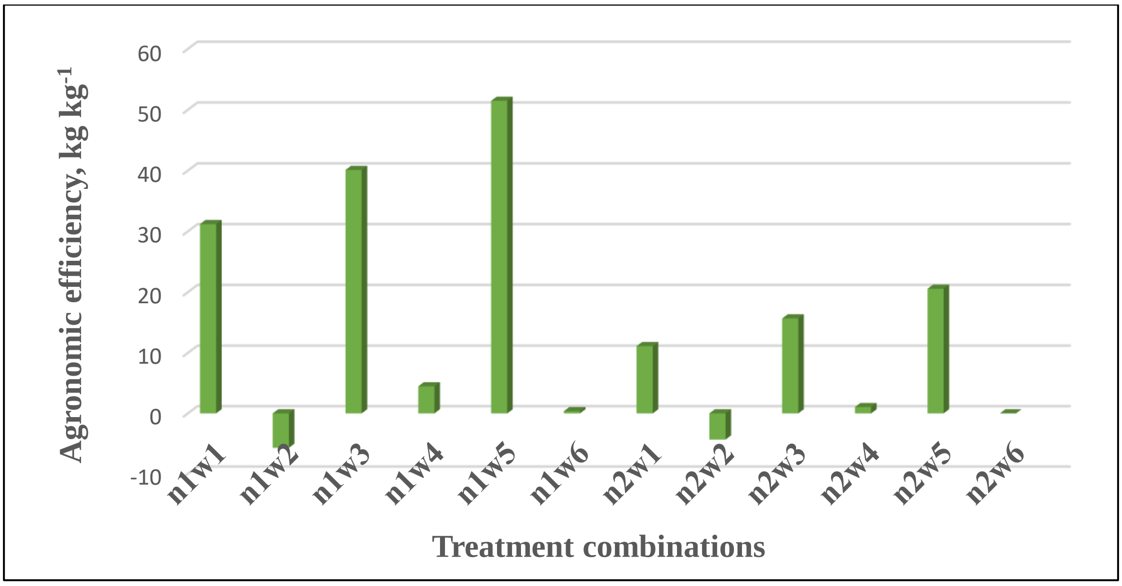

Fig 14. Interaction effect of nitrogen management and weed management practices on agronomic efficiency, kg kg^{-1}

management practices also had significant effect on total chlorophyll content. Increase in chlorophyll content was observed in oxyfluorfen plots which caused phytotoxic effect on okra. However, it is also possible that certain stress responses triggered by phytotoxicity could result in an increase in chlorophyll content as a protective mechanism. The nitrogen management, weed management, and their combination did not have a significant impact on the chlorophyll content at 60 days after sowing (DAS). Previous research indicated that after a specific period of growth in the presence of herbicide, pigment content could be lowered either by initiating pigment breakdown or by inhibiting the manufacture of either chlorophyll or carotenoids (Nakajima, *et al*. 1996).

Nitrogen is essential for achieving optimal yield and quality in okra cultivation. Out of the two nitrogen management practices, maximum crude protein content (17.6 %) was recorded with application of 100 per cent N as urea as per KAU POP (n_2). Naveen *et al*. (2017) pointed out that increasing level of nitrogen application in soil increased the crude protein content in okra. According to Sujin and Ruban (2007) the direct application of N to the soil enhanced the absorption of N and protein synthesis. Doses of N at 50 to 150 kg N ha^{-1} increased the levels of crude protein of okra by 6.8 to 20.7 per cent compared to those without N. Interaction between nutrient management and weed management was found significant in crude protein content. Among the treatment combinations, n_2w_3 has recorded the highest crude protein content (21.35 %) and it was on par with n_2w_5 (21.00 %), n_2w_2 (19.60 %) and n_1w_1 (18.58 %). Study conducted by Subbaiah and Ramanathan (1986) confirmed that crude protein content is related to the enhanced absorption of nitrogen in the soil and at high level, there is accumulation of non-protein nitrogen by the plant. Moreover, the herbicide application and hand weeding resulted in better control of weeds, lowering weed competition and increasing the availability of nitrogen. This helps in better accumulation and translocation of nutrients leading to the synthesis of aminoacid and protein.

Low crude fibre content is considered to be the most desirable character in okra. Crude fibre content was not significant by the application of nitrogen. Nitrogen application with nanourea (n_1) resulted in the highest crude fibre content (33.22 %). The dominant effect of nitrogen is likely to be the reason for reduction in crude fiber content in n_2. Studies indicated that increase in applied nitrogen decreased the crude fibre per cent. Early workers like Mani and Ramanathan (1981) reported that increased application of nitrogen decreased the crude fibre content by increasing the succulence of fruits. The highest crude fibre content was observed in hand weeding at 15 and 30 DAS (35.05 %). The weedy check plots had the least amount of crude fiber, possibly because of the abundant weed population in the plots without any weeding which competed with okra for resources. The results agreed with findings of Metwally and Din (2003) who noted reduced fibre content in pea (*Pisum sativum* L.) plants in weedy plot.

As an antioxidant, ascorbic acid is mostly present in green leaves and fruits. Photosynthesis, cell wall growth, cell expansion, and stress tolerance are just a few of the processes it takes part in. Among the nitrogen management practices, n_1 resulted in higher ascorbic acid content (22.0 mg per 100 g) compared to n_2 (20.69 mg per 100 g). Based on this finding, it can be deduced that nitrogen is distributed more quickly to fruits when applied through leaves as opposed to soil application. Sabir *et al*. (2014) reported increased ascorbic acid content by foliar application due to reduced loss of nutrients through decomposition or washing from the soil, as well as avoiding their interaction with the soil, increasing its efficiency. HW at 15 and 30 DAS produced the highest ascorbic acid content (25.04 mg per 100 g) among the methods of weed control. Kumar and Reddy (2013) reported the highest levels of ascorbic acid content in tomato fruits hand weeded at 20 and 40 DAT. The decreased availability and uptake of nutrients could be the reason behind the lower levels of ascorbic acid observed in the weedy check plots.

5.5 SOIL ENZYME ANALYSIS AS IMPACTED BY NITROGEN MANAGEMENT AND WEED MANAGEMENT

The results suggested that the dehydrogenase activity in soil was not affected by nitrogen management. However, significant change in soil dehydrogenase activity was observed under weed management and its interaction with nitrogen management. Dehydrogenase activity is an important bioindicator of soil quality and fertility. It has been reported that inorganic fertilization has relatively less effect on soil dehydrogenase

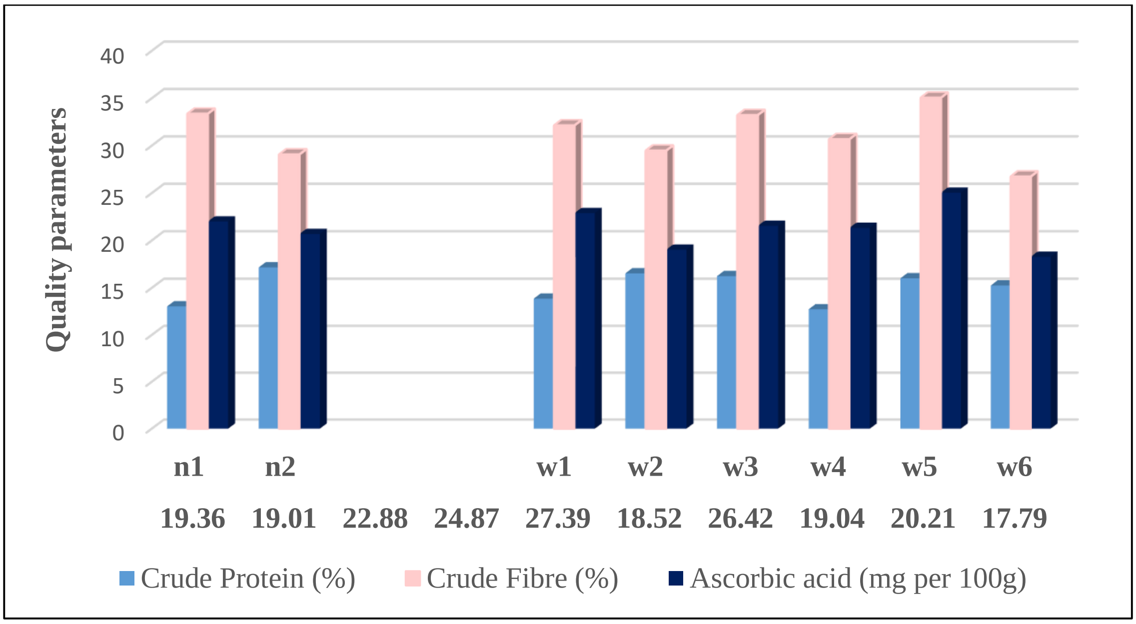

Fig 15. Effect of nitrogen management and weed management practices on quality parameters

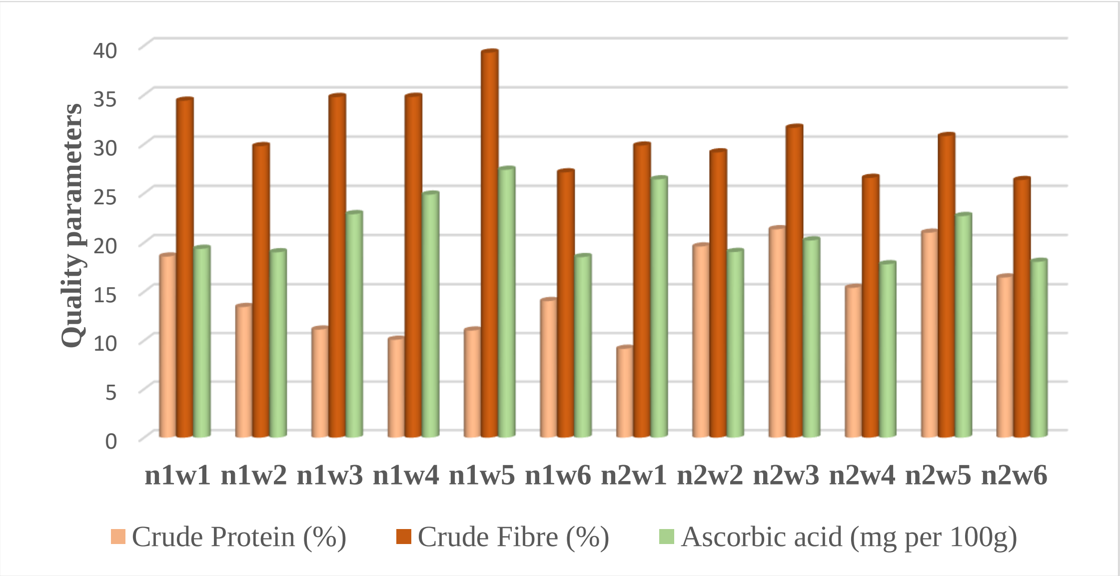

Fig 16. Interaction effect of nitrogen management and weed management practices on quality parameters

activity compared to organic fertilization (Macci *et al.*, 2012).

Pre- emergence pendimethalin at 1 kg ha^{-1} followed by hand weeding at 30 DAS (w_3) had higher dehydrogenase activity which was at par with hand weeding at 15 and 30 DAS (w_5). Any pesticide that has been applied to the soil has an effect on soil microbial population, as it is assumed that only 0.3 per cent reaches its target pest and the rest 97 per cent is released into environment (Muñoz-Leoz *et al.*, 2011). The increase in dehydrogenase activity might be due to the availability of carbon source to the microorganisms. Sireesha *et al.* (2012) reported that pre-emergence pendimethalin especially at lower doses increased dehydrogenase activity over control. The dip in dehydrogenase activity when oxyfluorfen is applied might be either due to the adverse effect on microbial population or due to presence of alternative acceptors. The dehydrogenase activity is dependent on the oxidation-reduction reactions and respiration of microbes occurring in soil. Presence of NO_2^- group in oxyfluorfen might act as alternate electron acceptor, thus reduce dehydrogenase activity and disturb the assay. The results are in accordance with Saha *et al.* (2015) and Gomez *et al.* (2014).

The interaction between nitrogen and weed management showed significant variation in dehydrogenase activity. Application of 50 % RDN + 0.2 % nano urea at 20 and 40 DAS along with two hand weeding at 15 and 30 DAS resulted in higher dehydrogenase activity (n_1w_5), followed by n_1w_3 which uses pendimethalin at 1 kg ha^{-1} followed by hand weeding at 30 DAS as weed control measure. The weed free environment provided by effective weed management along with the increased growth due to the use of nano nitrogen have resulted in healthier plants. Better root proliferation and exudation from roots of these might have resulted in increased microbial activity which ultimately led to increased dehydrogenase activity in soil.

Urease activity was not significant by nitrogen, weed management and their interaction. Higher urease activity was noticed in n_1 during 15, 30 and 45 DAS. This might be due to higher microbial activity corresponding to the comparatively healthier plants in n_1 over n_2. Hand weeding at 15 and 30 DAS (w_5) had higher urease activity, followed by pre-emergence application of pendimethalin at 1 kg ha^{-1} and subsequent hand weeding at 30 DAS (w_3). Conversely, a lower urease activity was observed from the plots treated with oxyfluorfen (w_2 and w_4). This might be due to the adverse effect of oxyfluorfen on survival of microbes. Bharathi *et al.* (2011) stated that application of certain herbicides may create osmotic stress and hindrance to survival of microbes, which in turn influences the soil enzyme activities.

The interaction between nitrogen and weed management on urease enzyme activity showed significant variation. At 15 DAS, the treatment n_1w_5 reported higher urease activity, followed by n_1w_3. The better growing condition provided to the plants due to absence of weeds, timely and sufficient availability of nitrogen, might have led to prolific growth and corresponding higher volume of root production. Vandana *et al.* (2012) reported that as the volume of roots in crop increases the associated soil enzyme activity also increases. The trend in urease activity remained same at 30 and 45 DAS, with higher urease activity in n_1w_5 followed by n_1w_3. However, a rise in urease activity was noticed in all the treatments at 30 DAS followed by a fall in 45 DAS. This sharp increase in urease activity coincides with the period of active growth in okra. The results are in accordance with the findings of Reddy *et al.* (2011) who reported increase in urease activity in 30 DAT in onion-radish cropping system and later it decreased.

5.6 PLANT NUTRIENT UPTAKE, NUTRIENT USE EFFCIENCY AND AVAILABLE NUTREINT STATUS AFFECTED BY NITROGEN MANAGEMENT AND WEED MANAGEMENT

From the results of the study, it was evident that nitrogen management practices have a significant influence on nitrogen uptake by haulm and total uptake by plants. Nitrogen management with nanourea enhanced the total N uptake by 13.42 per cent over soil application. The increased uptake could be attributed to a higher dry matter production and weed control efficiency. However, N uptake by fruit was not significantly affected by nitrogen management practices. This could be ascribed to the role of nitrogen in plant growing vegetatively resulting in higher haulm yield. Among the various weed management practices, hand weeding performed twice resulted in the highest nitrogen uptake by the haulm, fruit, and total uptake by the crop which was followed by pendimethalin with HW. Higher nitrogen uptake in hand weeding and pendimethalin fb HW plots could be related with the least weed dry weight and higher

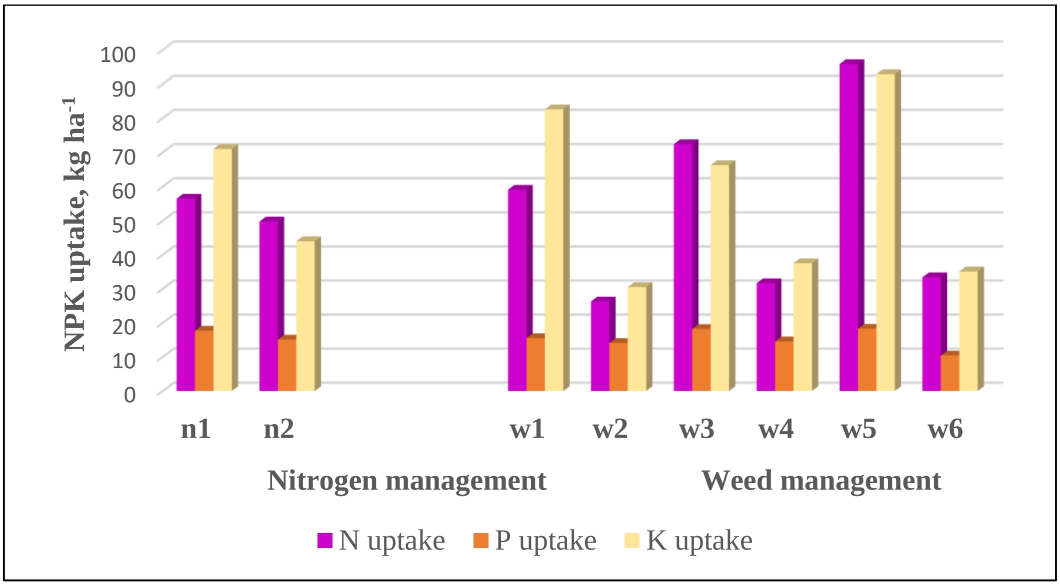

Fig 17. Effect of nitrogen management and weed management practices on NPK uptake by okra, kg ha^{-1}

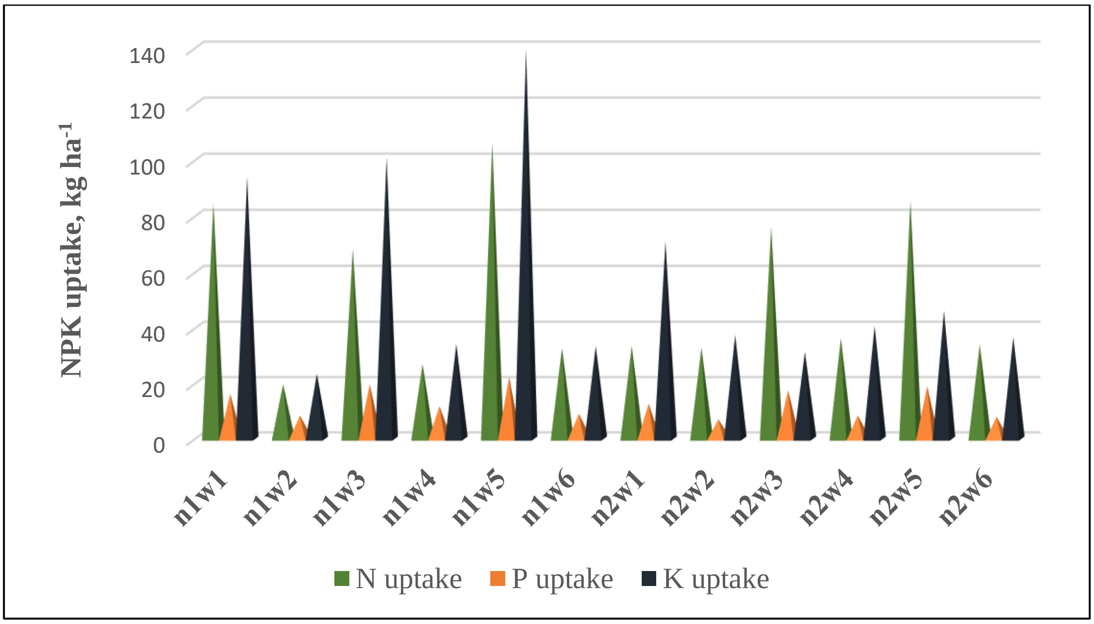

Fig 18. Interaction effect of nitrogen management and weed management practices on NPK uptake by okra, kg ha^{-1}

weed control efficiency. Reddy and Ameena (2021) found that by using weed control practices, NPK uptake by the crop could be raised by 49.42, 60.07, and 51.73 per cent, respectively, in comparison to a weedy check plot. Weedy check which represents the presence of weeds without any management, showed lower total nitrogen uptake both through haulm (18.73 kg ha^{-1}) and fruit (14.68 kg ha^{-1}). According to a study carried out in rice by Subhas and Jitendra (1998), it was found that hand-weeded plots demonstrated a higher level of nitrogen uptake compared to the weedy check and nitrogen uptake in the hand-weeded plots was reported to be twice as much as that observed in the weedy check.

Nitrogen management with nanourea and hand weeding resulted in the highest total N, P and K uptake by crop which was statistically significant. Higher nutrient availability with foliar nanourea application might have enhanced the availability and uptake of nutrients. Liu and Liao (2008) noted that the application of nano fertilizers on plant leaves was found to enhance the uptake of N, P, and K by plants leading to an increase in the production of dry matter. The highest crop NPK uptake was recorded in n_1w_5 which could be attributed to the effect of pendimethalin effectively eliminating weeds while nano nitrogen fertilization provided necessary nutrients for rapid plant growth, resulting in higher fruit yield, dry matter production and uptake. According to Reddy and Ameena (2021), pre-emergent spraying with herbicides accompanied by hand weeding increased the time span of effective weed control and helped the crop use the inputs more efficiently for better growth and dry matter production. This reduced the amount of nutrients that the weeds could use up and increased rice's ability to absorb nutrients.

The extent of nutrient loss by weeds varies from 30 to 40 per cent of the applied nutrients (Mundra *et al*., 2002). The data on weed nitrogen removal indicated that when nitrogen is applied to the soil, weeds tend to remove higher amounts of nitrogen compared to foliar application. By foliar application, the efficiency of applied nutrients could be increased. During the critical period of weed-crop competition, a greater removal of NPK was observed when nitrogen was applied to the soil in combination with application of oxyfluorfen and unweeded control. The phytotoxicity of oxyfluorfen and the consequent reduction in plant growth which persisted for upto three weeks could be attributed to the poor crop uptake and consequent higher weed removal. Umkhulzum (2018) reported lower crop nutrient uptake from weedy check due to intense crop-weed competition.

The post-harvest availability of nitrogen and phosphorus in the soil was not significantly affected by nitrogen management practices. However, the management practices used for weed control had a significant impact on the availability of phosphorus and potassium in the soil after harvest. The availability of nitrogen in the soil was observed to show enhancement by 43.99 per cent in hand weeded plots in comparison to its initial state. This could be attributed to the improved weed control, leading to a decrease in the amount of nutrients taken away by weeds. Reddy (2020) reported a decrease of 40.0, 13.2, and 28.4 per cent respectively, in available N, P and K levels in the soil, when compared to the initial levels. The data on nitrogen use efficiency revealed that foliar application of nanourea had a positive impact on nutrient use efficiency. The results clearly indicated that utilization of nano-scale nitrogen led to an enhancement in nitrogen uptake and utilization by the plants. Agronomic efficiency, apparent recovery efficiency and partial factor productivity were found to be the highest in n_1. Subramanian and Tarafdar (2011) noticed that the use of nano fertilizers could lead to a significantly increased nutrient use efficiency in maize, reaching up to 82 per cent, in comparison to conventional fertilizers.

5.7 ECONOMIC ANALYSIS AS IMPACTED BY NITROGEN MANAGEMENT AND WEED MANAGEMENT

The profitability of nitrogen management practices was enhanced by reducing the amount of soil application and supplementing it with nanourea generating a net income of ₹35,036 per hectare, whereas applying entire dose of urea to soil yielded ₹21,954 per hectare. In comparison to the usage of conventional fertilisers, Kumar *et al*. (2020) found that the application of 50 per cent urea and two sprays of nano-nitrogen generated the highest economic return (3,576 ha^{-1}).

The weed management practice that resulted in the highest net return (₹ 52588 per hectare) was HW twice. This was primarily attributed to the effective control of weeds and a reduction in competition between crops and weeds that enhanced the fruit

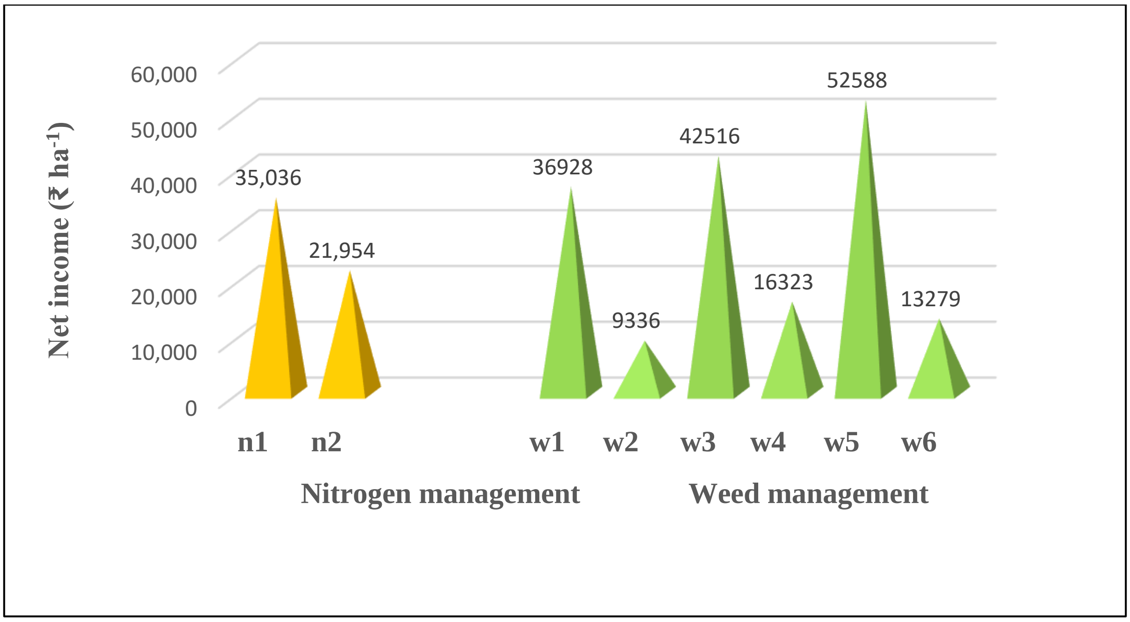

Fig 19. Effect of nitrogen management and weed management practices on net income (₹ ha^{-1})

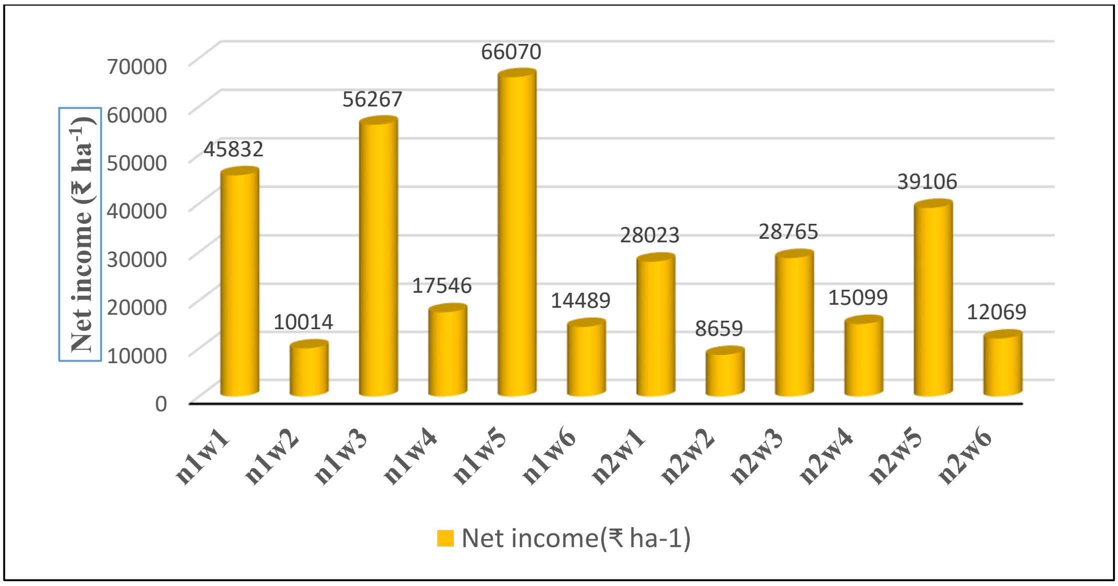

Fig 20. Interacion effect of nitrogen management and weed management practices on net income (₹ ha^{-1})

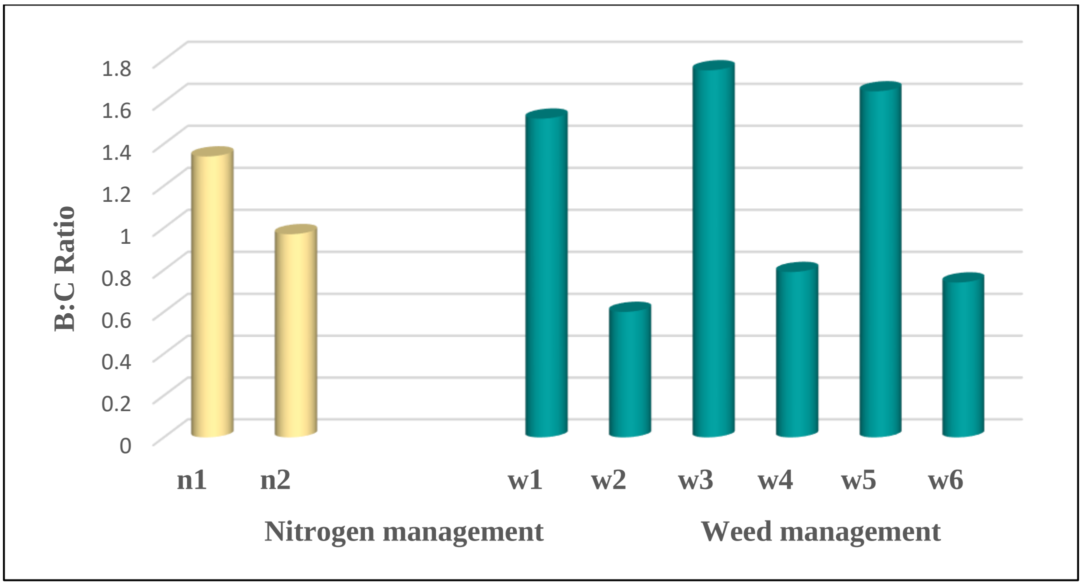

Fig 21. Effect of nitrogen management and weed management practices on B:C Ratio

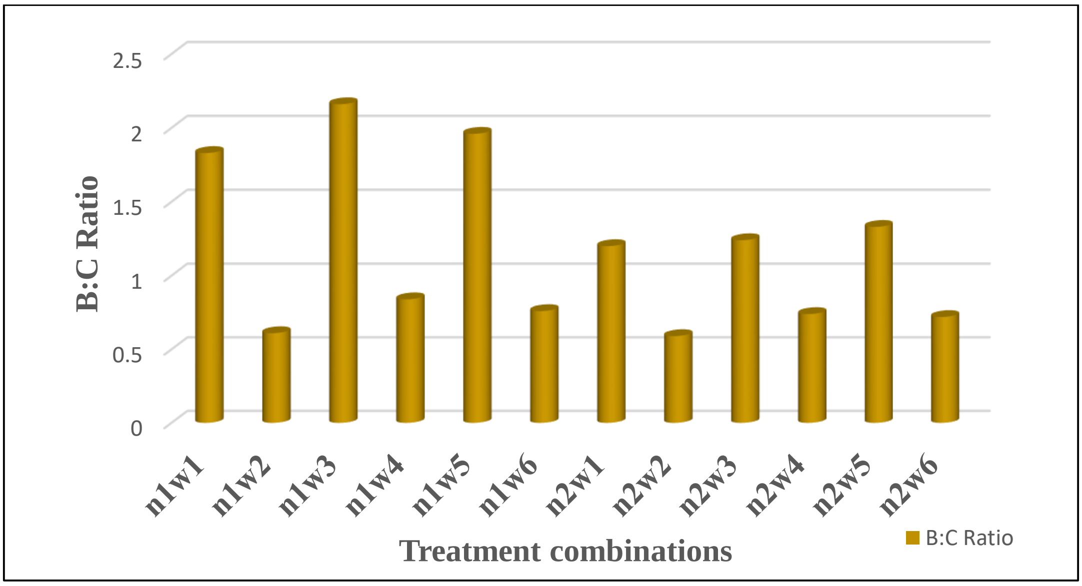

Fig 22. Interaction effect of nitrogen management and weed management practices on B:C Ratio

yield. However, the highest BC ratio was recorded in w_3 (1.50) as one hand weeding was replaced with herbicide. Herbicidal treatment was found to be more cost-effective, time-saving, and labour-saving compared to manual weeding in rice, despite the efficiency of hand weeding (Reddy and Ameena, 2021). The treatment combination n_1w_3 turned out to be the most economic weed management practice with a higher B:C ratio of 2.16. Singh *et al*. (2010), found that pendimethalin at 3 L ha^{-1} as pre-emergence with hand weeding at 45 DAS improved yield and economic returns in okra.

It could be concluded that nitrogen management and weed management have significantly enhanced the growth and yield of okra. Application of 50 per cent recommended dose of nitrogen as urea in soil + nano N as 0.2 per cent nanourea spray at 20 and 40 DAS (n_1) along with two hand weeding at 20 and 40 DAS turned out to be the most effective practice with respect to yield. Considering the economics, n_1 with pre-emergence pendimethalin at 1 kg ha^{-1} fb hand weeding at 30 DAS could be adjudged as the most effective nitrogen based integrated weed management practice in okra.

SUMMARY

6. SUMMARY

An investigation entitled 'Integrating weed management with nano nitrogen in okra (*Abelmoschus esculentus* (L.) Moench)' was conducted at College of Agriculture, Vellayani during January to April 2022. The major objective was to formulate an integrated weed management strategy based on nitrogen management using nano nitrogen to reduce crop weed competition in okra.

The field experiment undertaken at Instructional Farm, Vellayani, was laid out in randomised block design with 2 x 6 treatments replicated thrice. The treatments included combinations of nitrogen management [n_1 – 50 per cent recommended dose of nitrogen (RDN) as urea in soil (basal dose) + Nano N as 0.2 per cent nanourea spray at 20 and 40 days after sowing (DAS), n_2 - 100% N as urea as per KAU POP] and weed management practices [w_1- pre- emergence (PE) application of pendimethalin at 1 kg ha^{-1}, w_2- PE application of oxyfluorfen at 0.15 kg ha^{-1}, w_3- PE application of pendimethalin at 1 kg ha^{-1} followed by (*fb*) hand weeding (HW) at 30 DAS, w_4- PE application of oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS, w_5- HW at 15 and 30 DAS, w_6- weedy check].

The results of the study indicated significant influence for nitrogen management on all the growth attributes of okra. Half of the nitrogen applied as urea in soil and remaining as foliar application of nanourea at 20 and 40 DAS (n_1) resulted in taller plants at all the growth stages (43.96, 82.56 and 97.81 cm) with more number of branches (3.74) and leaves (15.23 and 9.37) compared to n_2. Amid the weed control techniques w_5 produced superior growth attributes followed by w_3 with taller plants (103.39cm), higher leaf area index (1.061) and dry matter production per plant (112.13 g per plant) while w_2 and weedy check had the least values for all growth attributes. The treatment combination n_1w_5 resulted in significantly higher dry matter production (120.96 g per plant) which was on par with n_1w_3 (117.16 g per plant) at harvest.

The yield attributes of okra were significantly affected by nitrogen management, weed management, and their interaction. However, no significant impact was observed on the days to 50 per cent flowering. Nitrogen management, n_1 has produced significantly more number of fruits per plant with the highest of 26.51, highest fruit length (15.13 cm), highest fruit weight (18.31 g) compared to n_2. The treatment w_5

resulted in the highest number of fruits per plant (32.43), highest fruit length (17.66 cm) and highest fruit weight (22.34 g) which was on par with w_3 (29.15, 16.38 cm and 20.82 g). The treatment combination n_1w_5 resulted in significantly more number of fruits per plant (37.30). Nitrogen management revealed that n_1 resulted in highest fruit yield per plant (614.28 g) and haulm yield per plant (50.07 g). Amongst the weed control methods, w_5 recorded highest fruit yield per plant (856.09 g) and haulm yield per plant (56.13 g). The treatment combination n_1w_5 recorded significantly more yield per plant (1070.22 g) as well as haulm yield per plant (61.9 g). Similarly, n_1 resulted in the highest fruit yield per hectare (2250 kg ha^{-1}) and haulm yield per hectare (1833 kg ha^{-1}) compared to n_2 (1563 kg ha^{-1} and 1608 kg ha^{-1}). The treatment w_5 was found to be significantly superior to other treatments and it has produced the highest fruit yield per hectare as well as haulm yield per hectare (3135 kg ha^{-1} and 2054 kgha^{-1}). n_1w_5 was found to be significantly superior and it has resulted in the fruit yield of 3920 kg ha^{-1} and a haulm yield of 2263 kg ha^{-1} which was on par with n_1w_3. n_1 resulted in higher harvest index (0.52) compared to n_2 (0.49). The highest harvest index was produced in w_5 (0.60). The highest harvest index was indicated by the combination n_1w_5 (0.65). n_2 resulted in more yield reduction with a weed index of 60.33 per cent compared to n_1 (42.59 per cent).The maximum yield reduction was recorded in w_2 with a weed index of 77.22 per cent. The highest weed index was indicated by n_1w_2 (78.15 per cent).

The experimental field exhibited the dominance of grasses as the primary weed flora, with broader diversity of broadleaf weeds; however, the diversity of sedges was limited to *Cyperus rotundus* L. The density of grass weeds was notably influenced by nitrogen management with nanourea application resulting in lowest density of grass weeds at 45 DAS (8.89 m^{-2}). The treatments w_4 (2.50 no. m^{-2}), w_2 (2.67 no. m^{-2}), w_3 (5.50 no. m^{-2}) and w_1 (6.00 no. m^{-2}) produced lower density of grass weeds at 15 DAS. However, at 45 DAS, w_4 has produced lowest grass weed density (6.67 no. m^{-2}). The lowest sedge density was recorded in the treatment combination n_2w_6 (0.00 no. m^{-2}). Oxyfluorfen (w_2 and w_4) resulted in least grass and BLW density at 15 DAS. The lowest dry weight of weeds at 45 DAS was observed in n_1 (8.77 g m^{-2}), compared to n_2 (15.43 g m^{-2}). And w_4 resulted in the lowest dry weight of weeds at 45 DAS (2.92 g m^{-2}) which was on par with w_3 (3.57 g m^{-2}) and w_5 (5.22 g m^{-2}). At 15 DAS, n_2w_2 had registered lowest weed dry weight(1.63 g m^{-2}). Similarly at 30 DAS, $n_1w_5$had registered lowest weed dry weight (1.39 g m^{-2}). At 30 and 45 DAS, n_1 resulted in higher weed control efficiency (WCE) (60.92 and 63.76 % respectively) than n_2 (54.95 and 49.42%, respectively). The treatment w_2 exhibited the highest WCE at 15 DAS (94.08%) while at 45 DAS, w_3 achieved the highest WCE (89.35%) which was comparable with w_5 (88.77). Yield reduction in okra due to uncontrolled weed growth in both n_1 and n_2 were estimated to be 69.88 and 70.36 per cent respectively.

Nitrogen management, n_1 resulted in lower relative density of grasses at 45 DAS (16.05 %). The density of grasses was lower by w_4 (0.00 %) which was on par withw_3 (11.25 %). The density of grasses recorded was lower in the combination n_2w_2 (0.00 %). The density of BLW was observed lower in w_4 (0.00 %). n_1 resulted in lower relative weed biomass of grasses at 15 (13.07 %) and 45 DAS (9.44 %) compared to n_2 (26.12 % and 31.01 %, respectively). At 15 DAS, the biomass of grasses observed was least in w_2 (2.96 %). At 30 and 45 DAS, biomass of grasses observed was lower in w_4 (9.80 % and 0.33 %, respectively). The biomass of sedges was produced lower by n_2w_2 (0.33 %). At 15 DAS, the relative biomass of broad leaf weeds was produced lower in w_4 (0.33 %). At 30 DAS, relative biomass of broad leaf weeds was produced lower in w_2(18.89 %) and it was on par with w_3 (21.55 %), w_4 (25.23 %), and w_6 (27.21 %).

Between the two practices, nitrogen management n_1 resulted in higher chlorophyll content (2.15 mg g^{-1}), crude fibre (33.36 %) on dry weight basis, ascorbic acid (22 mg $100g^{-1}$) on fresh weight basis, and agronomic efficiency (20.32 kg kg^{-1}). However, the crude protein content was higher in n_2. The highest dehydrogenase (165.0, 128.8 and 99.4 μg TPF g^{-1}soil d^{-1} respectively) and urease enzyme activity in soil at 15, 30 and 45 DAS (78.05, 109.27 and 57.14 μg urea hydrolysed g^{-1}soil $4h^{-1}$ respectively) were noticed in n_1w_5. Total NPK uptake of okra was higher in n_1 (56.45, 17.72, 70.99 kg ha^{-1}) than n_2. The highest N uptake by haulm (58.64 kg ha^{-1}), fruit (37.21 kg ha^{-1}) and total N uptake by crop (95.85 kg ha^{-1}) was produced by the treatment w_5 and it was significantly superior. The highest N uptake by haulm was recorded in n_1w_5 (70.71 kg ha^{-1}). The treatment combination n_1w_3 could be adjudged as the most economic weed management practice with a higher B:C ratio of 2.16.

Application of 50 per cent recommended dose of nitrogen as urea in soil + nano N as 0.2 per cent nanourea spray at 20 and 40 DAS (n_1) along with two hand weeding at 15 and 30 DAS (w_5) turned out to be the most effective practice with respect to growth, yield and nutrient uptake. Considering the economics, n_1 with pre-emergence pendimethalin application at 1 kg ha^{-1} followed by hand weeding at 30 DAS (w_3) could be adjudged as the most effective nitrogen based integrated weed management practice in okra.

Future lines of the work

➢ Experiment can be repeated for two or more seasons in different agro ecological units for confirmation of results.

➢ Varied doses of nano-N as foliar treatment can be tried in different crops for evaluating the effect on growth and yield of crops

➢ Compatibility of nano fertilizers as adjuvants for increasing herbicide use efficiency could be tried.

➢ Compatibility of oxyfluorfen herbicide in other solanaceous transplanted vegetables with different doses where the toxicity problem is not detected.

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ABSTRACT

INTEGRATING WEED MANAGEMENT WITH NANO NITROGEN IN OKRA
(*Abelmoschus esculentus* (L.) Moench)

by

NAVANEETHA C
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ABSTRACT

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ABSTRACT

An investigation entitled 'Integrating weed management with nano nitrogen in okra (*Abelmoschus esculentus* (L.) Moench)' was conducted at College of Agriculture, Vellayani during 2020-2022. The major objective was to formulate an integrated weed management strategy based on nitrogen management using nano nitrogen to reduce crop weed competition in okra.

The field experiment was undertaken at Instructional Farm, Vellayani during January 2022- April 2022, laid out in randomised block design with 2 x 6 treatments replicated thrice. The treatments included combinations of nitrogen management [n_1 – 50 per cent recommended dose of nitrogen (RDN) as urea in soil (basal dose) + nano N as 0.2 per cent nanourea spray at 20 and 40 days after sowing (DAS), n_2 – 100 per cent N as urea as per KAU POP] and weed management practices [w_1- pre emergence (PE) application of pendimethalin at 1 kg ha^{-1}, w_2- PE application of oxyfluorfen at 0.15 kg ha^{-1}, w_3- PE application of pendimethalin at 1 kg ha^{-1} followed by (*fb*) hand weeding (HW) at 30 DAS, w_4- PE application of oxyfluorfen at 0.15 kg ha^{-1} *fb* HW at 30 DAS, w_5- HW at 15 and 30 DAS, w_6- weedy check].

The results of the study indicated significant influence for nitrogen management on all the growth attributes of okra. Half of the nitrogen applied as urea in soil and remaining as foliar application of nanourea at 20 and 40 DAS (n_1) resulted in taller plants (97.81 cm) with more number of branches (3.74) and leaves (15.23) compared to n_2. Among the weed management practices, w_5 produced superior growth attributes followed by w_3 with taller plants (103.39 cm), higher leaf area index (1.061) and dry matter production per plant (112.13g) while w_2 and weedy check had the lowest for all growth attributes. The treatment combination n_1w_5 resulted in significantly higher dry matter production (120.96 g per plant) which was on par with n_1w_3 (117.16 g per plant) at harvest.

The yield attributes of okra were significantly influenced by nitrogen management, weed management, and their interaction. However, no significant impact was observed on the days to 50 per cent flowering. Nitrogen management with nanourea (n_1) resulted in more number of fruits per plant (26.51), fruit length (15.13 cm), fruit weight (18.31g), fruit yield per plant (614.28 g), haulm yield per plant (50.07

g) and harvest index (0.52) compared to n_2. Hand weeding at 15 and 30 DAS (w_5) produced more number of fruits per plant (32.43), fruit yield per plant (856.09 g), haulm yield per plant (56.13 g) followed by PE pendimethalin 1 kg ha^{-1} *fb* HW at 30 DAS (w_3). Fruit yield per plant and harvest index were the lowest with PE oxyfluorfen at 0.15 kg ha^{-1} (w_2). The treatment combination n_1w_5 resulted in higher number of fruits per plant (37.30), fruit yield (3920 kg ha^{-1}) and haulm yield (2263 kg ha^{-1}) followed by n_1w_3 (33.11, 3301 kg ha^{-1} and 2153 kg ha^{-1} respectively).

The experimental field exhibited the dominance of grasses as the primary weed flora, with broader diversity of broadleaf weeds; however, the diversity of sedges was limited to *Cyperus rotundus* L. The density of grass weeds was notably influenced by nitrogen management with nanourea application resulting in the lowest density of grass weeds at 45 DAS (8.89 m^{-2}). The lowest dry weight of weeds at 45 DAS was observed in n_1 (8.77 g m^{-2}), compared to n_2 (15.43 g m^{-2}). Oxyfluorfen (w_2 and $w_{4)}$ resulted in the lowest density of grasses and BLW at 15 DAS and w_4 resulted in the lowest weed dry weight at 45 DAS (2.92 g m^{-2}) which was on par with w_3 (3.57 g m^{-2}) and w_5 (5.22 g m^{-2}). At 30 and 45 DAS, n_1 resulted in higher weed control efficiency (WCE) (60.92 and 63.76 % respectively) than n_2 (54.95 and 49.42%, respectively). The treatment w_2 exhibited the highest WCE at 15 DAS (94.08%) while at 45 DAS, w_3 achieved the highest WCE (89.35%) and which was comparable with w_5 (88.77). Yield reduction in okra due to uncontrolled weed growth in both n_1 and n_2 were estimated to be 69.88 and 70.36 per cent respectively.

Between the two practices, nitrogen management n_1 resulted in higher chlorophyll content (2.15 mg g^{-1}), crude fibre (33.36 %) on dry weight basis, ascorbic acid (22 mg 100g^{-1}) on fresh weight basis, and agronomic efficiency (20.32 kg kg^{-1}). However, the crude protein content was higher in $n_{2.}$ The highest dehydrogenase (165.0, 128.8 and 99.4 µg TPF g^{-1}soil day^{-1} respectively) and urease enzyme activity in soil at 15, 30 and 45 DAS (78.05, 109.27 and 57.14 µg urea hydrolysed g^{-1}soil $4h^{-1}$ respectively) were noticed in n_1w_5. Total NPK uptake of okra was higher in n_1 (56.45, 17.72, 70.99 kg ha^{-1}) than n_2. The treatment combination n_1w_3 could be adjudged as the most economic weed management practice with a higher B:C ratio of 2.16.

Application of 50 per cent recommended dose of nitrogen as urea in soil + nano N as 0.2 per cent nanourea spray at 20 and 40 DAS (n_1) along with two hand weeding at 15 and 30 DAS (w_5) turned out to be the most effective practice with respect to growth, yield and nutrient uptake. Considering the economics, n_1 with pre-emergence application of pendimethalin at 1 kg ha^{-1} followed by hand weeding at 30 DAS (w_3) could be adjudged as the most effective nitrogen based integrated weed management practice in okra.

സംഗ്രഹം

“നാനോ നൈട്രജൻ വളങ്ങളിലൂടെ വെണ്ടയിലെ സംയോജിത കള നിയന്ത്രണം” എന്ന വിഷയത്തെ ആസ്പദമാക്കി വെള്ളായണി കാർഷിക കോളേജിൽ 2020-22 കാലയളവിൽ ഒരു ഗവേഷണ പഠനം നടത്തുകയുണ്ടായി. വെണ്ടയിലെ വിള - കള മത്സരം കുറച്ച് നാനോ നൈട്രജനെ പ്രയോജനപ്പെടുത്തി നൈട്രജൻ്റെ കാര്യക്ഷമമായ നിയന്ത്രണത്തിലൂടെ ഒരു സംയോജിത കള നിയന്ത്രണ മാർഗം ആവിഷ്കരിക്കുക എന്നതായിരുന്നു പ്രധാന പഠന ലക്ഷ്യം.

റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈനിൽ 12 ട്രീറ്റമെൻ്റ് ഉൾപ്പെടുത്തി ‘അഞ്ചിത’ എന്ന വെണ്ട ഇനം ഉപയോഗിച്ച് 2022 ജനുവരി മുതൽ ഏപ്രിൽ വരെയാണ് പരീക്ഷണം നടത്തിയത്. പാക്യജനകം യൂറിയ രൂപത്തിൽ മണ്ണിലൂടെ നൽകിയും മണ്ണിലും ഇലകളിലൂടെയും നാനോ യൂറിയ രൂപത്തിലും നൽകുന്ന വളപ്രയോഗം വിവിധ കളനിയന്ത്രണ മാർഗങ്ങളുമായി സംയോജിപ്പിച്ചുള്ള രീതികളാണ് പരീക്ഷണ വിധേയമാക്കിയത്.

കേരള കാർഷിക സർവ്വകലാശാലയുടെ ശാസ്ത്രീയ ശുപാർശകളുടെ പാക്കേജ് പ്രകാരം വെണ്ടയ്ക്കു നൽകേണ്ട മുഴുവൻ ഫോസ്ഫറസും (ഹെക്ടറിന് 35 കിലോ) പൊട്ടാഷും (ഹെക്ടറിന് 70 കിലോ) നേർ പകുതി നൈട്രജനും (ഹെക്ടറിന് 55 കിലോ) അടിവളമായി നൽകി. നൈട്രജൻ നിയന്ത്രണ മാർഗ്ഗങ്ങളുടെ ഭാഗമായി ശുപാർശ ചെയ്ത 50 ശതമാനം നൈട്രജൻ, മണ്ണിൽ യൂറിയ ആയി നൽകുന്നതിനൊപ്പം വിത്ത് വിതച്ച് 20, 40 ദിവസങ്ങളിൽ നാനോ യൂറിയ 0.2 ശതമാനം വീര്യത്തിൽ പത്രപോഷണം മുഖേന നൽകി, ശുപാർശ ചെയ്ത 100 ശതമാനം നൈട്രജൻ മണ്ണിൽ യൂറിയ ആയി രണ്ടു തവണ നൽകുന്ന രീതിയാണ് താരതമ്യം ചെയ്തത്. അതോടൊപ്പം ഹെക്ടറിൽ 1 കിലോ പെൻഡിമെതാലിൻ പ്രയോഗം, ഹെക്ടറിൽ 0.15 കിലോ ഓക്സിഫ്ലൂർഫെൻ പ്രയോഗം, ഹെക്ടറിൽ 1 കിലോ പെൻഡിമെതാലിൻ പ്രയോഗം തുടർന്ന് വിത്തു വിതച്ച് 30 ദിവസത്തിന് ശേഷം കൈ കൊണ്ടുള്ള കള നിയന്ത്രണം, ഹെക്ടറിൽ 0.15 കിലോ ഓക്സിഫ്ലൂർഫെൻ പ്രയോഗം തുടർന്ന് വിത്തു വിതച്ച് 30

ദിവസത്തിന് ശേഷം കൈ കൊണ്ടുള്ള കള നിയന്ത്രണം, വിത്തു വിതച്ച് 15, 30 ദിവസങ്ങൾക്ക് ശേഷം കൈ കൊണ്ടുള്ള കള നിയന്ത്രണം, കള നിയന്ത്രണം നടപ്പിലാക്കാത്തത് എന്നിങ്ങനെ 6 തരം കള നിയന്ത്രണ മാർഗങ്ങളും പരീക്ഷണ വിധേയമാക്കി.

ശുപാർശ ചെയ്ത 50 ശതമാനം നൈട്രജൻ യൂറിയ ആയി നൽകുന്നതിനൊപ്പം പത്രപോഷണം മുഖേന നാനോ യൂറിയ വിത്തു വിതച്ച് 20, 40 ദിവസങ്ങൾക്ക് ശേഷം നൽകുന്നതിലൂടെ വെണ്ടയിൽ മികച്ച വളർച്ചയും വിളവും ലഭിക്കുന്നതായി കാണപ്പെട്ടു. കളയുടെ അളവിൽ ഗണ്യമായ കുറവും കളനിയന്ത്രണ കാര്യക്ഷമത വർധിച്ചതായും അതോടൊപ്പം ചെടിയുടെ വളർച്ച, ശിഖരങ്ങളുടെയും ഇലകളുടെയും എണ്ണം, ജൈവാംശം, കായയുടെ എണ്ണം, തൂക്കം, കായ്കളിലെ മാംസ്യം, പോഷക ആഗിരണം എന്നിവയിൽ മികച്ച വർധനവും നിരീക്ഷിച്ചു. ഇതിൻ്റെ ഫലമായി അറ്റാദായത്തിലും വർദ്ധനവ് ഉണ്ടായി.

കള നിയന്ത്രണ മാർഗ്ഗങ്ങളിൽ വിത്തു വിതച്ച് 15, 30 ദിവസങ്ങൾക്ക് ശേഷം കൈ കൊണ്ടുള്ള കള നിയന്ത്രണം അവലംബിച്ചത് മുഖേന വിളകൾക്ക് മികച്ച തോതിലുള്ള വളർച്ചയും കായ്ഫലവും ലഭിക്കുകയും കളകളുടെ എണ്ണത്തിൽ ഗണ്യമായ കുറവ് കണ്ടെത്തുകയും ചെയ്തു. കൈ കൊണ്ടുള്ള കള നിയന്ത്രണം താരതമ്യേന കാര്യക്ഷമമായി അനുഭവപ്പെട്ടു എങ്കിലും അതിനു വേണ്ടി വന്ന സാമ്പത്തിക ചിലവ് മറ്റു കള നിയന്ത്രണ മാർഗ്ഗങ്ങളേക്കാൾ ഉയർന്നതായതിനാൽ സംയോജിത രീതിയിൽ ഹെക്ടറിൽ 1 കിലോ പെൻഡിമെതാലിൻ പ്രയോഗം തുടർന്ന് വിത്തു വിതച്ച് 30 ദിവസത്തിന് ശേഷം കൈ കൊണ്ടുള്ള കള നിയന്ത്രണ രീതി ആണ് വെണ്ടയിൽ ഏറ്റവും മികച്ച കള നിയന്ത്രണ മാർഗ്ഗമായി വിലയിരുത്തിയത്.

കേരള കാർഷിക സർവ്വകലാശാല ശുപാർശ പ്രകാരം വെണ്ടയ്ക്കു നൽകേണ്ട അടിവളങ്ങളോടൊപ്പം നാനോ യൂറിയ 0.2 ശതമാനം വീര്യത്തിൽ വിത്തു വിതച്ച് 20, 40 ദിവസങ്ങളിൽ പത്രപോഷണം മുഖേന നൽകുന്ന വളപ്രയോഗ രീതിയും ഹെക്ടറിൽ 1

കിലോ പെൻഡിമെതാലിൻ പ്രയോഗവും വിത്തു വിതച്ച് 30 ദിവസത്തിന് ശേഷം കൈ കൊണ്ടുള്ള കള നിയന്ത്രണവും അവലംബിക്കുന്നത് വെണ്ടയിൽ ഏറ്റവും മികച്ച സംയോജിത കളനിയന്ത്രണ രീതിയായി രേഖപ്പെടുത്തി.

APPENDIX

APPENDIX 1

Weather data during the crop season (10/01/2022 to 09/04/2022)

Standard week	Temperature (° C)		Relative humidity (%)		Mean bright sunshine hours	Total rainfall	Evaporation
	Maximum temperature (℃)	Minimum temperature (℃)	RH I	RH II		(mm)	(mm per day)
01	32.0	24.1	90.1	83.9	7.9	0.0	3.5
02	32.4	23.7	90.3	81.7	9.1	0.0	4.0
03	32.3	21.6	90.9	83.0	8.4	0.0	3.8
04	33.0	20.9	91.1	74.3	9.0	0.0	4.2
05	32.8	21.7	90.0	77.1	8.7	0.0	4.3
06	31.9	21.5	93.9	79.6	6.0	68.2	3.0
07	32.2	21.5	91.3	77.1	7.2	5.6	3.9
08	32.7	22.1	91.6	74.7	8.5	0.0	3.9
09	32.8	24.1	90.1	78.1	7.7	0.8	4.1
10	33.7	25.2	89.0	75.0	7.0	0.0	4.3
11	33.9	25.3	87.7	76.4	7.9	0.0	4.6