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John Debbarma

2025

EVALUATION OF HERBICIDES FOR WEED MANAGEMENT IN SOYBEAN (G*lycine max* L.) AND ITS RESIDUAL EFFECT ON SUCCEEDING LINSEED (*Linum usitatissimum*)

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR PHILOSOPHY

By

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BY

Name of candidate- John Debbarma

Name of Supervisor- Prof. L.Tongpang Longkumer

Submitted

In partial fulfillment of the requirements for the Degree of Doctor of

Philosophy in

Agronomy of Nagaland University

Dedicated

To

My dear family

Nagaland University
November, 2024

I, John Debbarma, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other university/institute.

This is being submitted to Nagaland University for the degree of Doctor of Philosophy in Agronomy

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CERTIFICATE – I

This is to certify that the thesis entitled **"Evaluation of herbicides for weed management in Soybean (*Glycine max* L.) and its residual effect on succeeding Linseed (*Linum usitatissium*)"** submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Agronomy is the record of research work carried out by Mr. JOHN DEBBARMA Registration No. Ph.D./AGR/00206 under my personal supervision and guidance.

The result of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

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CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN AGRONOMY

This is to certify that the thesis entitled **“Evaluation of herbicides for weed management in Soybean *(Glycine max L.)* and its residual effect on succeeding Linseed *(Linum usitatissium)*”** submitted by Mr. John Debbarma, Admission No. 303/19, Registration No. Ph.D./AGR/00206 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Agronomy has been examined by the Advisory Board and External examiner on ……………….............

The performance of the student has been found **Satisfactory/Unsatisfactory.**

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Date:
Place: SAS, Medziphema *John Debbarma*

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE NO.
1	INTRODUCTION	1 - 5
2	REVIEW OF LITERATURE	6 - 37
	2.1 Associated weed flora in soybean	
	2.2. Crop weed competition and yield losses caused be weeds	
	2.3 Effect of weed management practices on growth and yield of soybean	
	2.4 Effect on weed management on weeds	
	2.5 Effect of weed management practices on succeeding crop.	
	2.6 Residual effect of herbicide	
	2.7 NPK depletion by weeds and uptake by crop	
	2.8 Bioassay studies	
	2.9 Economics analysis on weed management	
3	MATERIALS AND METHODS	38 - 64
	3.1 General information	
	3.1.1 Site of experiment	
	3.1.2 Climate and weather conditions during the experiment period	
	3.1.3 Previous cropping history of the experiment field	
	3.1.4 Soil condition	
	3.2 Experimental details	
	3.2.1 Design and layout	
	3.2.2 Treatment details	
	3.2.3 Properties of herbicides use	
	3.2.4 Characteristics of variety	
	3.3 Cultural operations	
	3.3.1 Field preparation	
	3.3.2 Manures and fertilisers	
	3.3.3 Seed and sowing	
	3.3.4 Gap filling and thinning	
	3.3.5 Pest and diseases	
	3.3.6 Weed management treatments	
	3.3.7 Water management	
	3.3.8 Harvesting, threshing and winnowing	
	3.3.9 Succeeding crops	
	3.4 Sampling technique	
	3.5 Observation on weeds	
	3.5.1 Weed flora of the experimental field	

  - 3.5.2 Species wise weed count (no. m^{-2})
  - 3.5.3 Weed dry weight (g m^{-2})
  - 3.5.4 Weed control efficiency (%)
  - 3.5.5 Weed index (%)
- 3.6 Observation on crop
  - 3.6.1 Growth attributes
    - 3.6.1.1 Plant population (Linseed)
    - 3.6.1.2 Plant height
    - 3.6.1.3 Number of primary branches per plant
    - 3.6.1.4 Dry weight of plant (g $plant^{-1}$)
    - 3.6.1.5 Number, fresh and dry weight of root nodules
    - 3.6.1.6 Leaf area index
    - 3.6.1.7 Crop growth rate (g m^{-2} day^{-1})
    - 3.6.1.8 Relative growth rate (g g^{-1} day^{-1})
    - 3.6.1.9 Net assimilation rate (g m^{-2} day^{-1})
  - 3.6.2 Yield attributes
    - 3.6.2.1 Number of pods per plant
    - 3.6.2.2 Pod length
    - 3.6.2.3 Number of seeds per pod
    - 3.6.2.4 Seed index (g)
    - 3.6.2.5 Grain yield (kg ha^{-1})
    - 3.6.2.6 Stover yield (kg ha^{-1})
    - 3.6.2.7 Biological yield (kg ha^{-1})
    - 3.6.2.8 Harvest index (%)
- 3.7 Herbicide residue (bioassay studies)
- 3.8 Soil microbial analysis
  - 3.8.1 Bacteria (x 106 cfu g^{-1} soil)
  - 3.8.2 Actinomycetes (x 105 cfu g^{-1} soil)
  - 3.8.3 Fungi (x 103 cfu g^{-1} soil)
- 3.9 Chemical analysis
  - 3.9.1 Soil analysis
    - 3.9.1.1 Soil pH
    - 3.9.1.2 Electrical conductivity (d Sm^{-1})
    - 3.9.1.3 Organic carbon (%)
    - 3.9.1.4 Available Nitrogen (kg ha^{-1})
    - 3.9.1.5 Available Phosphorus (kg ha^{-1})
    - 3.9.1.6 Available Potassium (kg ha^{-1})
  - 3.9.2 Plant analysis
    - 3.9.2.1 NPK uptake by weeds (kg ha^{-1})
    - 3.9.2.2 NPK uptake by grain and stover (kg ha^{-1})
- 3.10 Economic analysis
  - 3.10.1 Cost of cultivation
  - 3.10.2 Net monetary return

3.10.3 Benefit cost ratio
3.11 Statistical analysis

4 RESULTS AND DISCUSSION 65 - 151
4.1 Observation on weed
4.1.1 Weed flora of soybean
4.1.2 Species weed count (no. m^{-2})
4.1.3 Weed density
4.1.3.1 Grasses (no. m^{-2})
4.1.3.2 Broad leaf (no. m^{-2})
4.1.3.3 Sedges (no. m^{-2})
4.1.3.4 Total weed density (no. m^{-2})
4.1.4 Dry weight of weeds
4.1.4.1 Total dry weight of grasses (g. m^{-2})
4.1.4.2 total dry weight of broad leaf (g. m^{-2})
4.1.4.3 Total dry weight of sedges (g. m^{-2})
4.1.4.4 Total dry weight of weeds (g. m^{-2})
4.1.5 Weed control efficiency (%)
4.2 Observation on crop
4.2.1 Growth attributes
4.2.1.1 Plant height
4.2.1.2 Number of primary branches per plant
4.2.1.3 Leaf area index
4.2.1.4 Dry weight of plant (g $plant^{-1}$)
4.2.1.5 Number of root nodules per plant
4.2.1.6 Number of fresh and dry weight of root nodules
4.2.1.7 Crop growth rate (g m^{-2} day^{-1})
4.2.1.8 Relative growth rate (g g^{-1} day^{-1})
4.2.1.9 Net assimilation rate (g m^{-2} day^{-1})
4.2.2 Yield attributes
4.2.2.1 Number of pods per plant
4.2.2.2 Pod length
4.2.2.3 Number of seeds per pod
4.2.2.4 Pod weight (g)
4.2.2.5 Seed index (g)
4.2.2.6 Grain yield (kg ha^{-1})
4.2.2.7 Stover yield (kg ha^{-1})
4.2.2.8 Biological yield (kg ha^{-1})
4.2.2.9 Harvest index (%)
4.3 Herbicide residue (by field bioassay)

4.3.1 Shoot length of test crops
4.3.2 Root length of test crops
4.4 Residual effect on succeeding
4.4.1 Plant population (m^{-2})
4.4.2 Plant height (cm)
4.4.3 Dry matter production
4.4.4 Seed yield (kg ha^{-1})
4.4.5 Economic analysis of succeeding crop
4.4.5.1 Cost of cultivation
4.4.5.2 Gross return
4.4.5.3 Net returns
4.4.5.4 Benefit: Cost ratio (B:C)
4.5 Soil microbial analysis
4.5.1 Soil bacteria (cfu g^{-1})
4.5.2 Soil fungi (cfu g^{-1})
4.5.3 Soil actinomycetes (cfu g^{-1})
4.6 Soil analysis
4.6.1 pH (Soil reaction)
4.6.2 Organic carbon (%)
4.6.3 Electrical conductivity (d Sm^{-1})
4.6.4 Available Nitrogen (kg ha^{-1})
4.6.5 Available Phosphorus (kg ha^{-1})
4.6.6 Available Potassium (kg ha^{-1})
4.7 Plant analysis
4.7.1 NPK uptake by weeds (kg ha^{-1})
4.7.1.1 Nitrogen uptake by weeds (kg ha^{-1})
4.7.1.2 Phosphorus uptake by weeds (kg ha^{-1})
4.7.1.3 Potassium uptake by weeds (kg ha^{-1})
4.7.2 NPK grain and stover crop (kg ha^{-1})
4.7.2.1 Nitrogen uptake in grain and stover (kg ha^{-1})
4.7.2.2 Phosphorus uptake in grain and stover (kg ha^{-1})
4.7.2.3 Potassium uptake in grain and stover (kg ha^{-1})
4.8 Economic analysis
4.8.1 Cost of cultivation (₹ ha^{-1})
4.8.2 Gross return (₹ ha^{-1})
4.8.3 Net return (₹ ha^{-1})
4.8.4 B:C ratio (₹ ha^{-1})
5 SUMMARY AND CONCLUSIONS 152-156
6 APPENDICES i-x

7 REFERENCES i-xviii

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
3.1(a)	Meteorological data recorded during the cropping season (2019)	41
3.1(b)	Meteorological data recorded during the cropping season (2020)	42
3.2	Previous cropping history of the experimental field	43
3.3(a)	Initial physico-chemical characteristics of the soil	43
3.3(b)	Initial chemical properties of soil	44
3.4	Detials of field operations carried out during experimentation	45
4.1.1	Weed flora of the experiment field	65-66
4.1.2	Effect of weed management on weed density (no. m^{-2}) of *Digitaria sanguinalis*	68
4.1.3	Effect of weed management on weed density (no. m^{-2}) of *Eleusine indica*	70
4.1.4	Effect of weed management on weed density (no. m^{-2}) of *Cynodon dactylon*	71
4.1.5	Effect of weed management on weed density (no. m^{-2}) of *Mollugo pentaphylla*	72
4.1.6	Effect of weed management on weed density (no. m^{-2}) of *Borreria latifolia*	75
4.1.7	Effect of weed management on weed density (no. m^{-2}) of *Mimosa pudica*	76
4.1.8	Effect of weed management on weed density (no. m^{-2}) of *Ageratum conyzoides*	77
4.1.9	Effect of weed management on weed density (no. m^{-2}) of *Amaranthus viridis*	80
4.1.10	Effect of weed management on weed density (no. m^{-2}) of *Portulaca olerecea*	81

4.1.11	Effect of weed management on weed density (no. m^{-2}) of *Alternanthera sessilis*	82
4.1.12	Effect of weed management on weed density (no. m^{-2}) of *Cleome rutidosperma*	84
4.1.13	Effect of weed management on weed density (no. m^{-2}) of *Cyperus rotundus*	85
4.1.14	Effect of weed management on weed density (no. m^{-2}) of *Cyperus iria*	86
4.1.15	Effect of weed management on weed density (no. m^{-2}) of grasses	88
4.1.16	Effect of weed management on weed density (no. m^{-2}) of broad leaf weeds	90
4.1.17	Effect of weed management on weed density (no. m^{-2}) of sedges	91
4.1.18	Effect of weed management on total weed density (no. m^{-2})	93
4.1.19	Effect of weed management on total dry weight of grasses (g m^{-2})	95
4.1.20	Effect of weed management on total dry weight of broad leaf (g m^{-2})	96
4.1.21	Effect of weed management on total dry weight of sedges (g m^{-2})	99
4.1.22	Effect of weed management on total dry weight of weeds (g m^{-2})	100
4.1.23	Effect of weed management on weed control efficiency (%)	102
4.1.24	Effect of weed management on weed index (%) in soybean	103
4.1.25	Effect of weed management on plant height (cm) of soybean (at 30,60 DAS and at harvest)	105
4.1.26	Effect of weed management on number of primary branches per plant (at 30,60 DAS and at harvest)	107

4.1.27 Effect of weed management on leaf area index (LAI) of soybean 108

4.1.28 Effect of weed management on dry weight of plant (g plant^{-1}) (at 30 and 60 DAS) 109

4.1.29 Effect of weed management on root nodules plant^{-1} of soybean (at 30 and 60 DAS) 110

4.1.30 Effect of weed management on fresh and dry weight of nodules plant^{-1} 113

4.1.31 Effect of weed management on Crop Growth Rate (CGR) (g m^{-2} day^{-1}) (at 30-60 DAS and 60-90 DAS) 116

4.1.32 Effect of weed management on relative growth rate (RGR) (g g^{-2} day^{-1}) (at 30-60 DAS and 60-90 DAS) 117

4.1.33 Effect of weed management on net assimilation rate (NAR) (g m^{-2} day^{-1}) (at 30-60 DAS and 60-90 DAS) 119

4.1.34 Effect of weed management on yield attributes of soybean 122

4.1.35 Effect of weed management on yield attributes of soybean (seed index & harvest index) 124

4.1.36 Effect of weed management on yield attributes of soybean (Grain & stover yield and biological yield 126

4.1.37 Effect of weed management on plant population, plant height, dry matter and yield of Linseed 132

4.1.38 Effect of weed management combination on economics of linseed cultivation 135

4.1.39 Effect of weed management on Soil microbial count (CFU g^{-1}) 136

4.1.40 Effect of weed management on soil nutrients status after harvest 138

4.1.41 Effect of weed management on soil available nutrients status after harvest 141

4.1.42 Effect of weed management on nutrient uptake by weeds (kg ha^{-1}) at harvest 143

4.1.43	Effect of weed management on nitrogen uptake by crop [grain and stover (kg ha^{-1})] at harvest	145
4.1.44	Effect of weed management on phosphorus uptake by crop [grain and stover (kg ha^{-1})] at harvest	146
4.1.45	Effect of weed management on potassium uptake by crop [grain and stover (kg ha^{-1})] at harvest	147
4.1.46	Effect of weed management combination on economics of soybean cultivation	150

LIST OF FIGURES

FIGURE NO.	CAPTION	IN BETWEEN PAGES
3.1(a)	Meteorological data recorded during the cropping season (2019)	42-43
3.1(b)	Meteorological data recorded during the cropping season (2020)	42-43
3.2	Layout plan of the experiment	45-46
4.1	Effect of weed management on total weed density (no. m^{-2})	93-94
4.2	Effect of weed management on total dry weight of weeds (g m^{-2})	100-101
4.3	Effect of weed management on weed control efficiency (%)	103-104
4.4	Effect of weed management on weed index (%) in soybean	103-104
4.5	Effect of weed management on yield attributes of soybean (Grain and stover yield & biological yield)	126-127
4.6	Effect of weed management on dry matter and yield of Linseed	132-133
4.7	Effect of weed management combination on Gross returns (₹ ha^{-1}) and Net returns (₹ ha^{-1}) of linseed cultivation	135-136
4.8	Effect of weed management combination on benefit cost ration (B:C)	135-136
4.9	Effect of weed management on nutrient uptake by weeds (kg ha^{-1}) at harvest	143-144
4.10	Effect of weed management combination on economics of soybean cultivation	150-151
4.11	Effect of weed management combination on economics of soybean cultivation	150-151

LIST OF PLATES

PLATE NO.	CAPTION	IN BETWEEN PAGES
1	Grasses weed observed in the experimental field	66-67
2	Sedges weed observed in the experimental field	66-67
3	Broadleaf weed observed in the experimental field	66-67
4	Effect of weed management on soybean	128-129
5	Soybean field at maturity	128-129
6	Soybean seed	128-129
7	Field of succeeding Linseed	135-136

LIST OF ABBREVIATION

%	Percentage
@	at the rate of
₹	Rupees
$^{-1}$ or /	Per
ai	active ingredient
BCR	Benefit Cost ratio
CD	Critical Difference
cm	Centimetre
DAA	Days after application
DAS	Days after sowing
df	Degree of freedom
et al.	*et allia* (and others/co-workers)
fb	Followed by
Fig.	Figure
g	Gram
ha	Hectare
i.e.	Id est (that is)
kg	Kilogram
M	Metre
m^2	Metre square
Max.	Maximum
Min.	Minimum
mm	Millimetre
MOP	Muriate of Potash
msl	Mean sea level
Mss	Mean sum of squares
mt	Million tonnes
NPK	Nitrogen Phosphorus Potassium
NS	Not significant
NU	Nagaland University
ºC	Degree Celsius
RDF	Recommended Dose of Fertilizers
SAS	School of Agricultural Sciences
SEm±	Standard error of mean
Sl. No.	Serial number
SOV	Source of Variation
ss	Sum of square
SSP	Single Superphosphate
t	tonnes
viz.	Videlicet (Namely)

ABSTRACT

A field experiment entitled “Evaluation of herbicides for weed management in soybean (*Glycine max* L.) and its residual effect on succeeding linseed (*Linum usitatissimum*)” was conducted in two consecutive years (2019 and 2020) during *kharif* seasons at the experimental research farm, Department of Agronomy, SAS, Medziphema. The experiment was laid out in Randomized Block Design (RBD), with different weed management treatments *viz*. T_1 : Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} pre-emergence, T_2 : Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} *fb* IC at 30 DAS, T_3 : Imazethapyr 10 SL @ 100 g a.i. ha^{-1} post-emergence, 20 DAS, T_4 : Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence *fb* IC at 30 DAS, T_5 : Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} post-emergence, 20 DAS, T_6 : Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} (10 DAS) early post-emergence *fb* IC at 30 DAS, T_7 : IC at 20 DAS *fb* Hand weeding at 40 DAS, and T_8 : Unweeded control and were replicated thrice. The pooled data results revealed that T_4 : Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence *fb* IC at 30 DAS recorded significantly the highest growth and yield attributes and yield of soybean *viz*. plant height (56.56 cm), number of branches (3.92), leaf area index (2.33), dry matter accumulation (14.77 g plant^{-1}), number of root nodules plant^{-1} (52.40), dry weight of nodules plant^{-1} (0.10 g), crop growth rate (7.94 g m^{-2} day^{-1}), net assimilation rate (1.35 gm^{-2} day^{-1}), number of pods plant^{-1} (56.62), grain yield (2005.26 kg ha^{-1}), stover yield (2347.13 kg ha^{-1}) and seed index (9.70 %). The dominant weed flora observed in the experimental field were *Mollugo pentaphylla, Borreria latifolia, Mimosa pudica*, *Ageratum conyzoides*, *Amaranthus viridies*, *Portulaca oleracea*, *Mollugo pentaphylla*, *Alternanthera sessilis*, *Cleome rutidosperma*, *Cyperus rotundus*, *Cyperus iria*, *Digitaria sanguanalis*, *Eleusine indica* and *Cynodon dactylon*. Among the weed management treatments, T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) recorded higher growth, yield attributes and yield of soybean followed by T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence *fb* IC at 30 DAS). It also recorded significantly the lowest weed population, weed dry weight, NPK depletion by weed and higher weed control efficiency. It was also found that NPK content and uptake by crops were also recorded maximum in T_7 (IC at 20 DAS *fb* Hand weeding at 40 DAS) and followed by T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence *fb* IC at 30 DAS). The residual effect of weed management on succeeding linseed showed no adverse effect on plant height at 30 DAS. However, a higher plant population at 30 DAS, the dry matter at 60 DAS (1.07 g) and seed yield of succeeding crop (659.08 kg ha^{-1}) was recorded highest under treatment T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence *fb* IC at 30 DAS) after T_7 (IC at 20 DAS *fb* Hand weeding at 40 DAS). The shoot and root length at 30, 60, 90, and 120 DAS of bioassay tested seed viz., oat, mustard, cucumber, and maize was found to be non-significant for all the applied treatments. The highest cost of cultivation was found at T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) followed by T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS). Economic analysis revealed that the maximum gross return, the net return was obtained from the treatment T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence – *fb* IC at 30 DAS) after treatment T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS). The highest B:C ratio (2.65 pooled value) was also registered under the treatment T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence *fb* IC at 30 DAS). Thus, from the experiment, it can be concluded that T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence *fb* IC at 30 DAS) for weed management could result in profitable production of soybean.

Keywords: Herbicides, Soybean, Linseed, Pendimethalin, Imazethapyr, Sulfentrazone, yield, weed control efficiency, economics.

CHAPTER I

INTRODUCTION

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] has long been cultivated as a major source of plant protein and oilseeds in human history. Soybean was introduced as a supplementary oilseed crop to overcome the edible oil shortage in the country in the mid-sixties and for a short period it has been considered an important agricultural crop grown commercially for its agro-economic value and diverse utilities in both the farming and industry sectors. It belongs to the Leguminaceae family, which has a subfamily *Papilionaceae* and a genus *Glycine*. It is reported to have originated in eastern Asia or China. In India, oilseed crops constitute the second largest agricultural produce, next to food grains and these are an important source of our national economy. It stands second, among nine oilseed crops, next only to groundnut production in the country.

Soybean is utilised for food, value-added products, and non-food purposes. Soybean is used to prepare food products like oil, soy flour, soymilk, soy paneer, soy nuts, candy sauce, extruded products, fortified traditional products, etc., and it is also used for non-food purposes, such as ink, cosmetics, biodiesel, textiles, fibreglass, etc.

The estimates of world soybean area, production and productivity for 2017-18 are 126.64 million ha, 346.31 million metric tonnes and 2.74 t ha^{-1}. The major soybean growing countries are the USA, Brazil, Argentina, China and India. India ranks fourth in terms of area under soybean and fifth in terms of production (AMIS, FAO February 2018). In India, the soybean area, production and productivity estimated for *kharif* 2018 are 10.84 million ha, 10.59 million tonnes and 11.48 t ha^{-1}. Soybean is gaining popularity on account of its unique characteristics and adaptability to varied agro-climatic conditions. It is grown in a large area of Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, Andhra Pradesh/ Telangana, and Chhattisgarh (SOPA, for *kharif* 2018). Soybean has been traditionally grown on a small scale in Himachal Pradesh, the Kumaon Hills of Uttar Pradesh (now Uttarakhand), eastern Bengal, the Khasi Hills, Manipur, the Naga Hills, and parts of Central India covering Madhya Pradesh (Dinesh *et al*. 2013).

In the North East Hill region, the productivity of soybeans is 1000 kg ha^{-1}, which is much higher than the national productivity level (822 kg ha^{-1}). Whereas, in Nagaland state, the total estimated area under soybean cultivation is 24,860 ha with a total production of 31,410 metric tons. (Anonymous, 2012 and 2017).

The primary sources of vegetable oils which are soybean (34 per cent), groundnut (27 per cent), rapeseed & mustard (27 per cent) contribute to more than 88% of total oilseeds production and >80 per cent of vegetable oil with a major share of mustard (35 per cent), soybean (23 per cent) and groundnut (25 per cent) (NMOOP, 2018). India is the fourth largest producer of oilseeds in the world accounting for about 19 per cent of the global area and 2.7 per cent of global production (Viswanatha and Kingsly, 2017) next only to the USA, China, and Brazil.

Soybean is considered a highly nutritive crop and plays an important role in supporting the agricultural economy of India. It contains 40 per cent good protein than other legumes and cereals (20-30 per cent and 8-15 per cent), 20 per cent oil, and other valuable components include phospholipids, vitamins, minerals, trypsin inhibitors, phytates, oligosaccharides and isoflavones (KeShun, 1997). Soybean contain 26 per cent carbohydrates, 4 per cent minerals and 2 per cent phospholipids (Halwankar *et al.* 1994). It is a rich source of vitamin A, B and D besides it contains the mineral salts Ca, Mg, Na, P, Fe, Cl, K and S. It also contains phytochemicals known as isoflavones which protect the human body against chronic diseases such as cancer, diabetes, osteoporosis, blood pressure, coronary heart disease etc. It is also the cheapest and best source of high-quality vegetable protein equivalent to meat, milk products and eggs, hence, it has earned epithets called “poor man’s meat,” “Cow of the field” or “Gold from soil”. In protein deficient countries, it is used in formation of low cost nutritionally balanced protein foods and drinks. Soybean serves as an oil seed crop, feed for animals, protein source for humans, and biofuel feedstock and industrial products therefore, it is called “Wonder crop.” Due to atmospheric nitrogen fixation in the soil to maintain the soil fertility beneficial effect on successive crops so called

“*Golden bean” or “Gold of soil*” and in the 21st century become a “*miracle crop”*. The crop is also visualized as a future energy crop for the production of biodiesel, an eco-friendly usage to meet the fuel energy requirements in several countries.

Soybean is a rainy season crop. Soybean initial growth is slow and crops face vigorous growth and proliferation of weed infestations. Weeds are one of the major deterrents for sustaining the crop productivity during *kharif* season. Weeds compete with the crops for nutrients, moisture, light and space; and reduce the yield and quality of produce. Besides, they also act as alternate hosts for insect pests and disease-causing organisms (Mishra *et al.* 2016). The first 20 - 45 days after sowing of soybean are considered to be critical with respect to weed-crop competition (Mishra, 2018). Weeds alone cause a reduction of 37 per cent soybean yield, while other fungal diseases and agricultural pests account for 22 per cent of losses (Oerke and Dehne, 2004). If weeds are not controlled during the critical period of weed-crop competition, there is a reduction in the yield of soybeans from 35 to 50 per cent depending upon the weed flora (Horvath *et al.* 2023). Therefore, weed management is the most important agronomic aspect that plays an important role in exploiting the yield potential of soybeans, provided other inputs are not limiting.

Competition between crops and weeds generally does not begin at the early stages after the emergence of the crop. If these weeds are checked during this period, the soybean gets an advantage over the weeds and smothers them afterwards. The introduction of herbicides has made it possible to control a wide spectrum of weed species effectively in pulses. Now numbers of herbicides are available in the market. Proper use of herbicides may manage weeds during the critical crop-weed competition period and thereby help in enhancing the productivity of crops.

Generally, soybean weed is managed through manual weeding and mechanical hoeing, but due to the unpredictability of rainfall and adverse weather conditions, along with non-workable soil conditions, manual weeding in a short span of time during kharif is neither possible nor feasible, and in a peak period of crop growth, labour is not easily available, and labour charges are also high because of the shifting of agricultural labour to industries for better and more assured wages. Therefore, to resolve this problem, chemical weed control through pre- or post-emergence herbicides is the only effective and feasible alternative left to control weeds during the critical phase of growth. Since it is low cost, less labour and time-demanding, and a target-specific method of weed control that covers a large area in a short time.

Herbicides are expected to control weeds by chemical means within the season of application, while it is unpredicted the persistence of herbicides in soil and their residual effect on the following crop growth. Although the use of herbicides creates public concern and receives much criticism from naturalists and environments, still herbicides are widely used for weed control. A farmer, using crop rotations, needs to know whether the phytotoxic properties of a compound have disappeared before planting a sensitive crop into a previously treated soil. A bioassay, using a sensitive crop in the treated soil as the growth medium, can provide useful information for each of these situations.

Now a days, a number of herbicides are recommended for the crop in the farmer's field, and the continuous application of herbicides in the intensive cropping system may lead to residue accumulation in soil. This causes considerable health hazards and environmental pollution. Residue studies are essential to determine the duration of herbicidal efficacy and effect on follow-up crops. Such studies have to be conducted in different soil and agro-climatic conditions.

Bioassay is a major tool for quantitative and qualitative determination of herbicide residues. In this method, the property of a chemical is measured in terms of some biological responses. Sensitive plant species called indicator or test species are used for conducting bioassays. The major advantage of this technique is that the procedure followed is generally more economical and easier to perform; costly equipment is not required. The indicator plant is grown in a field or pot and is compared with that of a similar plant grown in untreated soil.

Bioassay may be used to study the activity, persistence, and movement of herbicides in soils. The effects of various soil properties and environmental conditions on herbicide phytotoxicity and the absorption, movement, and degradation in plants.

Two basic assumptions are made when a bioassay is used: (a) the bioassay species will show an injury response in proportion to herbicide concentration, and (b) the response obtained is reproducible. A bioassay is generally used as a means of quantitative measurement of the biologically active concentration of a herbicide known to be present. However, bioassays sometimes may be used to determine the presence or absence of a particular herbicide. Generally, this task is more difficult because herbicides in the same family may produce similar symptoms. Some qualitative determination is possible.

It is therefore imperative to evaluate the performance of different herbicides under a given set of conditions for their efficacy. Such an attempt has been made here on soybean using postemergence herbicides in comparison with the farmer's cultural practices in order to evaluate the efficacy of different herbicides for control of weeds in soybean, and also to study the competitive effects of weeds on growth and yield of soybean, and the residual effect of herbicide has become one of the important factors for recommending it to the farmers in order to avoid the residual phytotoxicity in the succeeding crops.

Considering of all these important views, the present research work "Evaluation of herbicides for weed management in soybean (*Glycine max* L.) and its residual effect on succeeding linseed (*Linum usitatissimum*)" were undertaken with the following objectives.

1) To study the effect of weed management practices on growth and yield of soybean.

2) To evaluate the efficacy of weed management practices on associated weed flora in soybean.

3) To determine the phytotoxicity of different herbicides on succeeding linseed.

4) To study the relative economics of weed management practices in soybean and linseed cropping systems.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Weeds are the most severe biotic constraint to crop production and cause imperceptible damage in cropped and non-cropped land till the crop is harvested. In all soybean-producing countries, weeds are considered the number one problem with heavy crop yield losses due to weed interference despite progress made in research and extension of weed science. Competition between crops and weeds removes inputs (nutrients, water) applied to the soil, competition for primary resources (light, water, and nutrients), and the release of allelochemicals. Losses caused by weeds differ in the nature, extent and intensity of weeds, depending on the ecology in which the crop is grown.

Soybean is a widely growing legume that is consumed in many parts of the world. Soybean products are utilized for human consumption, animal feed, and the manufacture of several nonfood consumer and industrial products. This chapter includes a brief review of previous work and research findings on weed flora, critical weed competition and yield losses caused by weeds, their competitive effect on growth, yield, nutrient uptake by crop and weed in soybean, microbial activity, the effect of hand weeding, and the residual effects of pre- and post-emergence herbicides on succeeding linseed

2.1 Weed flora associated with soybean

To evolve a successful weed control programme, identifying and understanding of weed community associated with soybean is essential. Weed flora differs widely in their diversity depending upon environmental and soil conditions and hence the information on the weed spectrum in soybean fields will be of great use for the formulation of effective weed management practices.

From SAS, Nagaland, Walling *et al*. (2012) observed that the dominant weeds associated with soybean crop includes *Amaranthus viridis*, *Ageratum conyzoides*, *Cassia tora*, *Chromalaena odorata*, *Mimosa pudica* (among broad leaved), *Cynodon dactylon*, *Digitaria sanguinalis, Eleusine indica, Imperata cylindrica* (among grasses) and *Cyperus rotundus*, *Cyperus iria* (among sedges). Longchar and Longkumer (2015) reported that in State Agriculture Research Station, Mokokchung district, Nagaland, there the dominant weed flora were *Cyperus iria*, *Digitaria sanguinalis, Cynodon dactylon, Echinochloa colonum*, *Cyperus pylorus*, *Cyperus diformis*, *Plantago major*, *Ageratum conyzoides*, *Erechthites valerianai, Bidens pilosa* Linn, *Borreria hispida*, *Cammelena bengalensis*, *Centella asiatica, Euphorbia hista, Oxalis carymbosa* and *Oxalis corniculata*.

Panda *et al.* (2015) reported that *Echinochloa colona, Dinebra retroflexa, Cyperus rotundus, Cynodon dactylon, Alternanthera philoxeroides, Eclipta alba and Mollugo pentaphylla* were present at the Product Testing Unit, JNKVV, Jabalpur.

Prachand *et al*. (2015) observed in Akola (Maharashtra) different dicot weed species observed in experimental field were *Lagasia mollis, Euphorbia hirta, Digera arvensis, Tridex procumbense, Parthenium hysterophorus, Celosia argentea, Euphorbia geniculata, Alysicarpus rugosus, Alternanathera triandra, etc*. Different monocot weed species observed were *Commelina benghalensis, Dinebra arabica, Poa annua*, *Echinochloa crusgalli, Eragrostis major, Cynodon dactylon, Cyperus rotundus, etc*.

Nandini *et al.* (2016) noted that *Echinochloa colona and Cynodon dactylon* and *Cyperus rotundus, Cyperus iria,* and *Fimbristylis miliacea* were the sedges and among broad-leaved weeds, *Commelina benghalensis, Spilanthus paniculata, Galinsoga parviflora,Chenopodium album* and *Amaranthus spp.* were most common at the Research Farm, College of Agriculture, CAU, Imphal.

Sanbagavalli *et al.* (2016) noted broad leaved weeds were dominated and accounts to 73 per cent followed by grasses (16 per cent) and sedges (11 per cent). Major weed flora found in the experimental fields mainly consisted *Trianthema portulacastrum, Digeria arvensis, Gynanadropsis pentaphylla, Dactyloctenium* *aegyptium, Amaranthus viridis, Cynodon dactylon* and *Cyperus rotundus* in the experimental field, TNAU, Coimbatore.

Billore (2017) Indicated that experimental field was infested with the weed flora of *Parthenium hysterophorus, Digera arvensis, Acalypha indica, Commelina* spp., *Alternenthera* spp., *Corchorus* spp. and *Euphorbia geniculata* of broad-leaved weeds and *Dinebra arabica, Echinocloa* spp., *Brachiaria* spp., *Digitaria sanguinalis* and *Cynodon dactylon* of grassy weeds and *Cyperus rotundus* of sedges.

Parmar *et al.* (2017) observed the major weed flora of Central India in Soybean were *Echinochloa colonum and Commelina benghalensis* among the monocots and *Digera arvensis, Phyllanthus niruri, Trianthema monogyna, Corchorus olitorious,* and *Leucas* aspera among dicots were present whereas Cyperus rotundus was the only sedge.

Simaiya *et al.* (2017) noticed that the dominant weed flora associated with soybean were *Echinochloa crusgalli, Degiteria sanguinalis, Dinebra arabica, Cyperus rotundus, Commelina benghalensis, Acalypha indica, Eclipta alba, Caesulia axillaris, Digera arvensis, Corchorous acutangulus* and *Phyllanthus niruri* at Sehore, Madhya Pradesh.

Simaiya *et al.* (2018) observed the major weed flora in the experimental plot were the *Echinochloa colona, Echinochloa crus Galli, Digitaria marginata, Digera arvensis, Eclipta alba, Amaranthus viridis, Parthenium hysterophorus, Commelina benghalensis, Altrnenthra philoxeroides, Phylanthu sniruri and Cyperus rotundus* at Sehore, Madhya Pradesh.

Deshkari *et al.* (2019) noticed that the experimental field of soybean was infested with *Cyperus rotundus, Lagasca mollis, Digera arvensis, Parthenium hysterophorus, Celosia argentea, Euphorbia spp. Alternanathera triandra, Phyllanthus niruri, Commelia bengalensis* at Nagpur, Maharashtra.

Vanisree *et al.* (2019) reported that predominant weed species associated with soybean in Nagpur, Maharashtra were *Digera arvensis, Parthenium hysterophorus,* *Euphorbia hirta*, *Celosia argentia*, *Tridex procumbense*, *Euphorbia geniculata*, *Alternanathera triandra* among the dicot weeds and *Commelina benghalensis*, *Dinebra Arabica*, *Poa annua*, *Echinocloa crusgalli*, *Cyanodon dactylon*, *Eragrostis major among* monocot weeds.

Shukla *et al*. (2020) reported that major weed flora associated with soybean are *Chenopodium album*, *Convolvulus arvensis*, *Abutilon theoprasti*, *Amaranthus spinosus*, *Amaranthus hybridus*, *Amaranthus tuberculatus*, *Protolactus oleracea*, *Solanum nigrum*, *Bidens pilosa*, *Baltimora recta*, *Parthenium hysterophonus*, *Melampodium diranicatum*, *Tridax procumbuens* were the broad leaved weeds and sedges were *Cyperus rotundus*, *Cyperus esculentus*, *Xanthium pensylvanicum*, *Sida spinosa*, grasses *Imperata cylindrica*, *Cynodon dactylon*, *Pennisetum clandestinum*, *Setaria virids*, *Setaria faberii*, *Setaria veticillata*, *Centhrus* spp, *Echinochloa colona*, *Eleusine indica*, *Rottboellia exaltata*, *Rottboellia cochinchinensis*, *Eleusine africana* and *Digitaria* spp.

The predominant weed species noticed in soybean crop at Jabalpur, Madhya Pradesh were *Echinochloa colona*, *Cyperus iria* among the monocots and *Sida acuta*, *Mollugo pentaphylla*, *Phyllanthus urinaria* among the dicots (Patel *et al*. 2021).

Apon and Nongmaithem (2022) reported that thirteen (13) species of weeds were noted in the SAS, Nagaland field where research was conducted i.e., grasses (*Cynodon dactylon*, *Digitaria sanguinalis* and *Eleusine indica*); sedges (*Bulbostylis barbata*, *Cyperus kyllingia*, *Cyperus iria*,); and BLW-broad leaved weeds (*Amaranthus viridis*, *Ageratum conyzoides*, *Borreria latifolia*, *Cleome rutidosperma*, *Mimosa pudica* and *Mollugo pentaphylla*).

Barla *et al. (*2022) mentioned that weed flora associated with soybean in Birsa Agricultural University, Ranchi were *Dactyloctenium aegyptium*, *Echinochloa colona*, *Eleusin indica* and *Digitaria sanguinalis* among grassy weeds, *Stellaria media*, *Commelina benghalensis* and *Phyllanthus niuri* among broad leaved and *Cyperus rotundus* among sedges weeds were dominant.

Dhakad *et al.* (2022) noticed the dominant weed flora associated with soybean were *Echinochloa crusgalli, Echinochloa colona, Commelina benghalensis, Panicum dichotomiflorum, Polygonum spp., Aeschynomene indica, Digitaria sanguinalis, Eleusine aegyptium and Cyperus spp*. at Kota, Rajasthan.

Kumar *et al*. (2022b) observed the major weed flora in soybean crop on clay loam soils at Raipur, Chattisgarh was *Cyperus rotundus* among the sedges, broad-leaved weeds like *Euphorbia spp., Trianthema portulacastrum, Digera arvensis, Amaranthus viridis* and *Phyllanthus niruri* and the grasses like *Echinochloa, Acrachne racemosa, Dactyloctenium aegyptium, Digitaria sanguinalis, Eragrostis pilosa* and *Commelina benghalensis.*

Kutariye *et al*. (2022) reported monocot weeds like *Echinochloa colona*, *Dinebra retroflexa*, *Cyperus rotundus*, *Cynodon dactylon* and dicot weeds like *Eclipta alba*, *Mollugo pentaphylla*, *Alternanthera philoxeroides* as major weed flora in Jabalpur, Madhya Pradesh.

Meena *et al.* (2022) noted that predominant weeds observed in soybean on clay loam soils of Kota, Rajasthan were *Cynodon dactylon*, *Eleusine indica*, *Echinochloa crusgalli* and *Echinochloa colona* among grassy weeds, *Digera arvensis*, *Boerhavia diffusa*, *Commelina benghalensis*, *Convolvulus arvensis*, *Celosia argentea* among broad leaved weeds and *Cyperus rotundus* among sedges.

2.2. Crop weed competition and yield losses caused by weeds

Identification for critical periods of crop weed competition is vital for a given crop growing period when crops are most sensitive to weed competition for their primary resources (light, water, and nutrients), affects crop growths and results in maximum damage to crops which leads to severe reduction of economic yields. It helps with effective and economical strategies of weed management practices thereby minimizing the negative impacts of weeds environmentally and economically. Various workers have established the critical period of crop weed competition in soybean.

Van Acker *et al*. (1993) and Chhokar and Balyan (1999) observed weed competition for soybean occurs around the fourth node growth stage, or 30-35 days after emergence (DAE). When compared with unweeded control, there was a 74% increase in soybean grain yield.

Oerke and Dehne (2004) reported weeds alone cause an average reduction of 37 per cent on soybean yield, while other fungal diseases and agricultural pests account for 22 per cent of losses.

Andre Rodrigues dos Reis and Vivian (2011) reported that the density and distribution of weed species in the soybean plantations are significant parameters on yield losses, as the weed species competes with the sunlight, water and nutrients, and may, depending on the level of infestation and species, hamper harvesting operations and compromise the quality of soybean grains.

Walling *et al*. (2012) stated that in Nagaland, weed competition in soybean is between 14 and 54 days after sowing.

Fickett *et al*. (2013) estimated a 27% soybean yield loss, whereas Silva *et al*. (2013a) reported that weed interference throughout the entire soybean crop cycle at low, medium, and high weed densities resulted in 73%, 82%, and 92% lower soybean grain yield, indicating that yield potential may not be fully protected by delayed weed control practices beyond optimal weed development phases.

Gupta *et al* (2014) revealed that crop-weed competition in soybeans is most important during the first 45 DAS as it can result in production losses of 10%–86% depending on the severity of the weed infestation.

Jha *et al*. (2014) reported that depending on the type, severity, and persistence of the weeds, weed competition can significantly lower yields during the early stages of soybean crop growth by up to 58–85%.

Francisco de *et al*. (2015) identified that the key time for weed management in soybean is between 7 and 42 DAE to minimize yield losses, whereas Stefanic *et* *al*. (2015) established the critical period for weed between 2 and 8 weeks adhering to crop emergence.

Panda *et al*. (2015) observed yield reduction due to presence of weeds in soybean was maximum (63.1 per cent) in weedy plots and similarly, (Yadav *et al.* 2017) also reported reduced soybean seed yield by 37-54 per cent.

According to Soliman *et al.* (2015) soybean growing seasons with severe weed infestation had the lowest yield and seed yield losses, reaching 38.93%.

Akter *et al*. (2016a) reported that depending on the kind of soil, the season, and the intensity of the weed infestation, the reduction in soybean yield caused by weed infestation ranges from 20 to 77%.

Gholipouri (2016) demonstrated that weed treatment for soybeans between 10 to 40 days after emergence (DAE) was critical to avoid yield loss in of 10%. Critical weed control occurs until the fifth week following emergence with the use of weed management.

Mishra *et al*. (2016) indicated weeds are one of the main obstacles to maintaining agricultural productivity. Weeds lower agricultural output and quality by competing with crops for nutrients, soil moisture, sunlight, and space. Further, they serve as diverse hosts for pest insects and pathogens.

Parmar *et al*. (2016) noted that being a rainy-season crop, soybeans are greatly susceptible to weed infestation, resulting in yield reductions ranging from 20 to 71% depending on the type, severity, and prevalence of weeds.

Carkner and Entz (2017) observed that weeds caused yield losses in soybeans ranging from 20 to 44%, although timely weed management was found to have a positive impact on yield losses.

Soltani *et al.* (2017) revealed that weeds are one of the most significant, and controllable, threats to crop production. Monetary losses because of reduced soybean yield by about 52% in the absence of any weed management and decreased quality because of weed interference, as well as costs of controlling weeds, have a significant economic impact on net returns to producers and yield loss estimates were determined from comparative observations of soybean yields between the weedy control and plots with greater than 95 per cent weed control in his studies.

Suryanto *et al.* (2017) reported soybean yield decreased significantly when the weedy period was done after 14-42 days after planting. The soybean yield was influenced by the dry weight of annual weeds (DRAW), heterogeneity of weed, soil moisture, phosphorus and potassium concentration in the tissue. The critical period of weed control in soybean for acceptable yield loss of 5, 10, 15 and 20 per cent began 16, 21, 24 and 27 days after emergence and ended 61, 55, 53 and 49 DAE.

According to Gharde *et al.* (2018), three factors-location, crop, and soil type have significantly impacted the variability in yield losses in soybeans (50–76%) caused by weeds in farmers' fields.

Mishra (2018) noticed that crop-weed competition for soybeans develops 20-45 days after planting and Daramola *et al.* (2020) suggested that soybeans should be weed-free 3 to 6 weeks after sowing for optimal growth development and yield.

Patidar *et al.* (2019b) observed weeds reduced soybean productivity by 58 to 85 percent depending on the species and severity and were responsible for the highest reduction in seed yield (78.50%).

Chauhan (2020) observed few factors that affect the amount of soybean output lost to weeds, which accounts for an estimated 31% of losses, are weed emergence time, weed density, and weed species.

Kanatas *et al.* (2020) reported that weed competition is the primary cause of the 80% yield loss in soybean cultivation that is occurring globally, putting 37% of the potential supply of soybeans in peril.

Panneerselvam and Lourduraj (2000) have reviewed from different locations in India that the critical period of soybean crop-weed competition is up to 45 days after sowing.

Nimu *et al*. (2020) from Bangladesh reported that weed-free up to 60 DAS in soybean emerged as the promising one regarding seed yield and quality. Whereas, Alam *et al*. (2022) from Indonesia observed that the beginning of the critical period of weeds for soybeans generally begins from 20-59 DAE.

Zain *et al.* (2020) revealed that in many parts of the world, weed interference in soybean cultivation can diminish grain yield and profit by up to 80%, which frequently raises production costs and reduces profit and product quality.

Kumar *et al*. (2022a) reported that crop's critical period is the brief window in its life cycle when weeds must be kept out of the crop to minimize weed damage. If weed control is not performed during this time, losses will not be compensated until the weeds have been controlled.

Mamudu and Adeyemi (2022) observed that 4–8 weeks affected the critical period of weed interference in soybean growth and yield.

Kaur *et al*. (2024) reported that crops and weeds compete for resources such as water, light, space, and nutrients, which has a negative impact on the targeted crop, resulting in delayed growth development and yield losses. The ability to interfere is determined by a variety of factors, including weed species and density.

2.3. Effect of weed management practices on growth and yield of soybean

Tandale and Ubale (2007) reported that according to the pooled data, the highest RGR peaked between 30 and 60 DAS and declined between 60 and 90 DAS till crop harvest. There was a noticeable positive correlation between the RGR and seed yield during 30 and 60 DAS.

Abdelhamid and El-Metwally (2008) found that increase in soybean production and the components it contains can be linked to its superior ability to get rid of weeds, which in turn reduces the competition between these weeds and the crops, allowing the crops to grow more effectively. Furthermore, the significant impact of hoeing on the quality of the soil, including aspects like soil composition, drainage, and the availability of certain nutrients, cannot be overlooked. Therefore, these outcomes might be a consequence of decreased competition for essential resources like nutrients, water, and sunlight, achieved through the use of hoes or herbicides that enhance nutrient absorption.

According to Kumar *et al*. (2008) the yield-contributing characteristics branch count per plant, pod count per plant, seeds per pod, and 1000-seed weight-increased with an increase in herbicide dosage, which in turn affected the seed production. Nonetheless, it was comparable to twice-hand weeding as effective as all preemergent herbicides when compared to them all.

Priya *et al*. (2009) found highest 1000-seed weight of 111.03 g was recorded with an alachlor+HW treatment compared to the control; it was 53% higher. The second-best treatment was observed at two HWs, which recorded 106.9 g; however, the control treatment had the lowest weight of 1000 seeds (76.63 g).

Meena and Dhaka (2013) reported that two hand-weeding at 20 and 35 DAS recorded significantly higher filled pods plant-1 (41.90), seeds/pod (3.33), seed index (12.20 g), seed yield (14.85 q ha^{-1}) and return (₹ 24,460 ha^{-1}) over other treatments. The highest benefit: cost ratio (1.72) was obtained with 1 kulpa at 20 DAS+1HW at 35 DAS. Significantly lower weed density (40.70 m^{2}), weed dry weight (366.30 kg ha^{-1}) at harvest and highest weed control efficiency (56.78%) and return (₹ 21,500 ha^{-1}) were obtained with use of Imazethapyr 75 g ha^{-1} at 15 DAS + 1HW at 35 DAS over rest of treatment.

As the period of weed-free increased, so did the weight of fresh and dry nodules per plant (Mirjha *et al*. 2013).

Gupta and Chandrakar (2014) in their experiment conducted at Raipur, Chhattisgarh indicated the minimum weed index and highest weed control efficiency, the growth characters like plant height, number of branches and dry matter production was maximum under hand weeding twice at 20 and 40 DAS which was found comparable with sulfentrazone @360 g a.i. ha^{-1} as PE, and imazethapyr @ 100 g a.i. ha^{-1} as PoE.

Habimana *et al.* (2014) observed from his field experiment conducted at zonal agricultural research station, University of agricultural sciences, (UAS) Bengaluru. The results revealed that intercultivation *fb* hand weeding at 20 and 40 DAS recorded higher grain and haulm yield (2570-2964 kg ha^{-1}), lower weed population and their dry weight (8.00 number and 1.00 g 0.25 m^{-2}, respectively), no. of pods per plant (165), pod weight per plant (77 g plant^{-1}), no. of grains per pod (2.79) and hundred grains weight (19.18 g). However, pre-emergence application of metribuzin *fb*. imzethapyr and metribuzin *fb*. intercultivation at 30 DAS gave lower weed population, dry weight and higher grain, haulm yield, no. of pods per plant, pod weight per plant, no. of grains per pod and 100 grains weight as compared to other herbicide treatments and unweeded check.

Vimal and Phajage (2014) revealed that due to various weed management, all yield-attributing characteristics, such as branches plant^{-1}, leaf area index (LAI), and dry matter productions, were significantly varied. Under weed-free conditions, a significant maximum of number of branches plant^{-1} (3.67), LAI (9.25) and dry matter production (1.2 kg m^{-2}) were recorded followed by application of imazethapyr.

Chandraker and Paikra (2015) revealed that following pre-emergence, application of imazethapyr 100 g ha^{-1} *fb* one hoeing at 20 DAS and pendimethalin 1000 g ha^{-1} supplemented with one hand weeding at 20 DAS resulted in the lowest weed growth rate, density, and dry matter production of weeds and the maximum weed control efficiency. Application of imazethapyr 100 g ha^{-1} *fb* one hoeing at 20 DAS obtained the highest seed yield and harvest index, while pendimethalin 1000 g ha^{-1} *fb* hand weeding at 20 DAS obtained the highest stover yield. Under weedy check, a high weed index was observed.

Dhaker *et al.* (2015) found that chemical and physical weed management techniques greatly decreased the amount of dry matter and the density of weeds. The least number of weeds and dry matter (58.24% less than weedy check) were found in the two hoeing and weeding operations.

Jakhar and Sharma (2015) opined that decrease in crop-weed and insect competition led to an increase in the growth rate of soybeans. The increased sink size was able to store photosynthates more efficiently, which in turn led to an increase in the accumulation of dry matter and a higher relative growth rate, weed-free plots exhibited a higher CGR value in soybean, and CGR values increased during 30-60 DAS compared to 60 DAS to harvest.

Kale *at al*. (2015) reported that two hand weeding at 15 and 30 days after sowing in soybean were shown to be more effective in keeping weeds under control during the crop growth period and in enhancing growth characteristics such as plant height, number of branches per plant, and plant dry matter (g). The two-hand weeding at 15 and 30 DAS produced the highest grain production, which was at par with the application of imazethapyr + imamox at 10 DAS and imazamethazpyr at 10 DAS.

Kumar *et al*. (2015) discovered that there was less crop weed competition in summer mungbean with the treatment of Imazethapyr @ 100 g/ha which produced the maximum root biomass (0.29 g plant^{-1}), nodule number (21.0 plant^{-1}), and nodule dry weight (3.57 mg plant^{-1}) at 40 DAS.

Akter *et al.* (2016) observed that the maximum amounts of pods plant^{-1}, pod length, seeds pod^{-1}, stover, and biological yield ha^{-1} were observed by two hand-weeding approaches (20 and 40 DAS, respectively), and these finding were statistically comparable to herbicide treatment.

Bali *et al*. (2016) conducted a field experiment was during *kharif* at Chatha, Jammu to evaluate the effect of weed management practice on growth, yield, yield attributes and quality of soybean. The lowest weed density, weed dry matter, highest yield attributes and seed yield (15.52 q ha^{-1}) was recorded in weed free followed by hand-weeding at 15 and 35 days after sowing (15.28 q ha^{-1}) and imazethapyr @ 75 g a.i ha^{-1} + hoeing at 35 DAS (15.08 q ha^{-1}).

Kumar *et al*. (2016) reported the highest plant dry weight was observed in weed-free, which is comparable to imazethapyr at 100 g ha^{-1}. Imazethapyr at 100 g ha^{-1} considerably increased the number of nodules and their dry weight, maximum root biomass putting them on par with weed-free nodules. This may be because these treatments result in lower crop weed completion.

Kurrey *et al*. (2016) reported that the senescence of leaves contributes to the lowered rate of crop growth, perhaps weeds compete with crops for solar radiation and grow more densely during these periods.

Patil *et al*. (2017) found that plant height is the primary indicator of growth because it led to the production of more leaves and, eventually, larger leaf areas, which enhanced the plant's ability to photosynthesis. When comparing the weed-free check to the weedy check, the total number of branches was substantially higher. There may have been fewer branches in the weedy check due to the challenging conditions the weeds provided, but more branches were present in the weed-free check because all the growth nutrients were always available. There may be less rivalry between agricultural weeds and an environment that supports soybean growth in its early phases, which could account for the increased number of branches.

Ahirwar *et al*. (2018) revealed that two hands weeding at 20 and 45 DAS resulted in the highest number of plants, dry matter accumulation of plants at harvest, number of branches, pod, seed index, and B:C ratio, all of which were considerably greater than with weedy check.

Bramhankar *et al*. (2018) reported the decline in NAR with increase in LAI. The Net assimiliation rate (NAR) was higher during 30-60 DAS that declined rapidly during 60-90 DAS and increased steadily towards maturity.

Daramola *et al*. (2018) observed the negative correlation between weed species density, canopy height, and leaf area index might be attributable to the good ground cover given by soybean canopy, which smothers weeds.

Deivasigamani and Swaminathan (2018) evaluated that a crop's grain yield is ultimately determined by environmental factors and agronomic management, being 100-grain weight indicative of a better yield.

Kaur *et al*. (2018) revealed that both underground/soil (water and nutrients) and aboveground/aerial (sunlight, space, atmospheric gases, etc.) resources are shared by weeds and crops. Crop-weed competition alters the utilization of resources and influences intricate relationships between plants and the environment. Weeds are a major threat to crop productivity because they are more aggressive, adaptable, and persistent than crops. Agricultural yields are generally decreased since weed can thrive in harsh situations and take up more water and nutrients from the land.

Kaziu and Kashta (2018) observed that elevated NAR values were observed in the vegetative phase, but a reduction occurred during the flowering phase. Conversely, low NAR values could be attributed to limited availability of crucial nutrients, reduced photosynthetic efficiency, or a decreased rate of biomass production as leaves age, and potentially to insufficient nutrients in later stages.

Korav *et al*. (2018) reported that plant height, dry matter accumulation, leaf area index, and physiological parameters like CGR, RGR, NAR, chlorophyll content, and leaf thickness are among the growth and development parameters that are reduced when the initial weed competition period is increased. In the same way, increased weed competition significantly lowers crop output.

Kumar *et al.* (2018) reported that hand weeding (20 and 40 DAS) was statistically at par comparable to post-emergence treatment of propaquizafop + imazethapyr, which increased LAI, CGR, seed, and straw production while considerably reducing the dry weight of weed.

Patil *et al.* (2018) conducted a field experiment was carried out during kharif at instructional farm, Junagadh Agricultural University, Junagadh to evaluate the suitable integrated weed management practices for soybean. Result indicated that integration of herbicides like Pendimethalin @ 0.750 kg ha^{-1} pre-emergence + 1HW and IC at 20 DAS recorded significant reducing in weed dry matter and higher weed control efficiency resulting in higher yield.

Rao (2018) conducted a field experiment at Agricultural College farm, Rajendranagar. Hyderabad, Telangana State and observed that application of pendimethalin @ 1.0 kg a.i ha^{-1} as pre-emergence followed by one hand weeding at 25 DAS can be recommended to realize higher yields. At harvest the number of pods plant^{-1} (33, 32), number of seeds pod^{-1} (3.0, 3.1), test weight (g) (12.5, 12.8), seed yield (17.21, 17.35q ha^{-1}), haulm yield (25.18, 25.34 q ha^{-1}) was recorded significantly highest in hand weeding at 25 and 45 DAS in two years respectively which was on par with pendimethalin @ 1.0 kg a.i ha^{-1} as preemergence followed by hand weeding at 25 DAS. The result eulogies the need for a crop weed free condition during the critical 4-6 weeks after sowing to harness the yield potential of soybean.

Anand *et al.* (2020) found that plant height, numbers of branches plant^{-1}, number of pods plant^{-1} were significantly higher with weed free check which was on par with integrated weed management of application of pendimethalin 38.7% CS 1.0 kg a.i. ha^{1} as Pre-emergence + hand weeding at 5th week after sowing and hand weeding twice at 3rd and 5th week after sowing.

Chaudhari *et al.* (2020) indicated that maximum seed yield and gross realization of was achieved under IC *fb* HW at 20 and 40 DAS while net realization of and BC ratio of 2.51 was recorded under application of propaquizafop + imazethapyr PoE (PM) closely followed by imazethapyr 100 g/ha PoE *fb* IC +HW at 30 DAS and fluazifop-p-butyl + fomesafen g/ha PoE (PM). The plant stand, plant height and dry matter production of wheat, chickpea and mustard were not affected by the application of different herbicides in preceding soybean.

Ghogare *et al.* (2020) found that weedy check control treatment had the lowest CGR during 60 and 75 DAS, while manual weeding twice produced the significantly greatest CGR. After then, the rate of CGR reduced between 45 and 60 DAS and then increased again between 60 and 75 DAS.

Anusha *et al.* (2021) opined that CGR was found to be higher and reached its peak between 30 and 60 DAS and slightly declined at 90 DAS. Variation in crop growth rate attributed to weed-free condition at critical period of crop and enhanced vegetative growth with better source-sink relationship to accumulate enough dry matter.

Dhayal *et al*. (2022) indicated that reduced crop weed competition obtained *via* manually weeding twice and using all herbicidal weed control measures led to an improvement in black gram grain production. Higher grain yields are the result of these factors' significant increases in growth and yield character. When there are weeds in the soil, they take up more of the resources and the surrounding environment, which helps them flourish throughout the early phases of crop growth.

Ahirwar and Ahirwar (2023) opined that weed-free treatment produced significantly the highest number of seeds per pod and influenced the heaviest weight of 100 seeds, respectively, when manual weeding was applied twice at 20 and 40 DAS. Weeds grown freely in the weedy check yielded the lowest 100-seed weight. Application of herbicide shows a promising impact, obtaining values higher test weight than the weedy check.

Bijarnia *et al*. (2023) reported that when pendimethalin + imazethapyr (RM) 750 g ha^{-1} *fb* manual weeding at 40 DAS was applied pre-emergence, the highest CGR, RGR, NAR, and LAI at various growth stages were recorded. While an indirect effect might be less competition for plant growth factors of production like light, space, water, nutrients, etc., the increased clusterbean growth parameters mentioned above appear to be mostly the result of various weed management practices directly reducing crop-weed competition.

Horvath *et al*. (2023) found that direct competition for resources is generally considered the primary mechanism for weed-induced yield loss. Weeds initially impact crop growth and development through resource-independent interference. Weed perception by crops induces a shift in crop development before resources become limited, which subsequently decreases crop yield, even if weeds are later removed.

Katoch *et al*. (2023) observed that the highest dry matter accumulation in the crop was probably caused by more effective weed control techniques, despite indications that the lowest dry matter accumulation was observed under the weedy check treatment. Using those methods, the primary crop and weeds are less likely to compete for vital resources like light, nutrients, and moisture. As a result, the application of efficient weed control treatments reduces the total competition between weeds and crops, which significantly improves crop development as shown by an increase in the accumulation of dry matter. This increase in dry matter buildup increases the efficiency of photosynthetic translocation to the sink and has a stream-flow effect on the crop's reproductive structures.

Kotnake and Goud (2023) opined that higher weed control efficiency and lower weed index may be attributed to reduced dry weight and increased seed production. In weed-control treatments, hand-weeding at 20 and 40 days after sowing (DAS) observed maximum number of branches per plant, weed management effectiveness, shoot dry weight per plant, number of nodules, and dry weight per plant were also recorded.

Shani *et al.* (2023) reported that at 30, 60, and at harvest, weed control treatments were visible on the number of plant’s branches. As it progressed, the crop reached its peak value in every treatment at harvest time. The lack of competition from weed crops could explain this, enabling the crops to grow at a faster pace. This would have allowed for improved growth and development and, ultimately, more branches per plant. Weed control treatment plots had the greatest branches per plant at 60 DAS, whereas weedy check plots had the fewest branches per plant.

Vishwakarma *et al.* (2023) opined that when compared to nutrient uptake in seed and straw under control, various herbicidal treatments using cultural methods showed a significant response in nutrient uptake. This enhanced crop growth, increased grain and straw yields, and, ultimately, increased nutrient uptake because the crop had adequate space and light due to increased weed control in herbicidal treatments during critical stages of crop growth.

According to Shwetha *et al*. (2024) reported soybean is vulnerable to weed interference because the seeds are sown with wide spacing to produce branches and to allow the canopy to extend fully during the late development period. Weeds are more easily developed in soybeans than in other crops due to late canopy closure.

2.4. Effect of weed management on weeds

Krausz *et al*. (1998) reported that Sulfentrazone at 280 g ai ha^{-1}.and at 420 g ai ha^{-1} controlled most of the monocot and dicot weeds at 92 to 100 per cent 56 days after planting (DAP) and 80 to 94 per cent 21 DAP. Sulfentrazone caused no visual soybean injury and did not reduce yield compared with standard herbicides.

Kundu *et al* (2011) indicates that the pre-emergence application of pendimethalin @ 125 g ha^{-1} showed the lower weed control efficiency in soybean at throughout the growing season of soybean.

Meena *et al*. (2011) reported that application of imazethapyr XL 10 per cent SL at 150 g ha^{-1} as post emergence significantly reduced the density of all grassy, broad leaf weeds sedges and their dry weight, and provided maximum number of branches plant^{-1}, pods plant^{-1}, seeds pod^{-1} and seed yield as compared to weedy check and imazethapyr 10 per cent at 50 g ha^{-1}. Infestation of weeds throughout the growth period caused 57.2 per cent reduction in seed yield of soybean.

Devi *et al*. (2012) noticed that hoeing and hand weeding (30 DAS) registered the highest leaf area index number of pods plant^{-1} with the next best treatment with weed control efficiency.

Ologbon and Yusuf (2012) reported that hoeing and hand weeding can maximize crop output, reduce weed growth, and boost agricultural yields when the frequency of weeding increases, the proliferation of weeds substantially slows down.

Peer *et al.* (2013) revealed that application of Pendimethalin 1.0 kg ha^{-1} integrated with one hand weeding at 35 DAS (critical period of weed removal) is the most appropriate method for effective weed management and profitable cultivation of soybean. Other methods are either less profit earners or are labour expensive.

Sikka *et al.* (2013) found that two-hand weeding at 20 and 40 DAS were equally effective for both weed control and influencing soybean production.

Monsefi *et al.* (2014) reported that hand weeding is a traditional and efficient method of weed control but its main drawbacks include inappropriate continuous rains and a lack of labour during peak times.

Satyakumari and Sagarka (2014) revealed that there was significantly higher uptake of nutrients by crop at weed free and lower uptake by weeds were recorded with HW & IC at 20 & 40 DAS followed by pendimethalin 30 per cent EC @ 0.900 kg ha^{-1} as PE + imazethapyr @ 75 g ha^{-1} as POE at 20 DAS, pendimethalin 30% EC @ 0.900 kg ha^{-1} as PE + HW & IC at 40 DAS, and propaquizafop @ 90 g ha^{-1} as POE at 20 DAS + HW & IC at 40 DAS.

Bajwa *et al*. (2015) found that the most common weed control technique employed by smallholder farmers in India is repetitive soil tillage followed by manual weeding.

Kunz *et al.* (2015) reported that inter culture is a promising substitute for chemical weed control that can be applied both within and between crop rows. Only manual weeding completely gets rid of all weeds. When normal hoeing and harrowing were utilized, soybean yields improved by 28% with the hand weeding plots producing the highest yield.

Kumar *et al.* (2016) observed that weed control efficiency value was lowest in the treatment imazethapyr, with the lowest value of weed dry weight and weed control index. The summer season application of imazethapyr was found to be highly effective in controlling the grassy weed population, even at very low doses.

Lal *et al.* (2016) revealed that hand weeding twice (20 and 40 DAS) surpassed the herbicidal treatments and was more effective than other treatments and resulted in the highest yield than any herbicidal approach.

Weber *et al.* (2016) reported that pre+post emergence application of different herbicides resulted in 92 to 99 per cent weed control efficiency and 15 per cent yield increase compared to the untreated control. The combination of pre+post emergence harrowing and hoeing resulted in 82 per cent weed control efficiency and 34 per cent higher yield compared to the untreated control. Less weed control efficiency (72 per cent) was observed in the harrow treatment, leading to 20 per cent higher yield compared to the control.

Borana *et al*. (2017) illustrated that pre-emergence treatment of pendimethalin 0.75 kg ha^{-1} + hand weeding 30 DAS produced the lowest density of monocots, dicots, and total weeds in comparison to the weedy check and yielded the lowest weed control efficiency.

Billore (2017) conducted an experiment on the bioefficacy of pre-mix formulation of herbicide at Malwa region Madhya Pradesh. Among herbicidal treatments, maximum weed control efficiency (83.08 per cent) and highest seed yield (2,030 kg ha^{-1}) was with imazethapyr @ 100 g a.i. ha^{-1} applied as post-emergence and remained at par with pre-mix formulation of sulfentrazone + clomazone @ 870 / 725 g a.i. ha^{-1} was found to be effective against major weeds of soybean.

Chaman *et al.* (2017) observed that weed control efficiency at harvest was the highest with two hand weeding (83.71 per cent) closely followed by ready mix of imazamox + imazethapyr 75 g ha^{-1} (77.14 per cent), imazethapyr alone (73.76 per cent), pendimethalin +1 HW (64.24 per cent), quizalofop-ethyl (34.40 per cent) and clodinafop-propargyl (32.08 per cent).

Dawood (2017) found that two-hand hoeing was the best to approach for improving plant height, yield, yield attributes, and chemical composition of soybean seeds. This technique also produced the highest weed depression represented in the lowest dry matter of broad leaved, narrow-leaved, and total weeds.

Ferdous *et al.* (2017) reported that two hand weeding (HW) at 20 and 40 DAS recorded the highest seed yield and the lowest was found from no weeding treatment. The enhancement in the seed yield due to various weed control measures was because of the fact that they helped to keep the field comparatively free from weeds, thus resulted probably in better utilization of resources namely, nutrients, moisture, solar light etc.

Gupta *et al*. (2017) found that the weed index indicates a loss in yield compared to hand weeding at 20 and 40 days after sowing. The control plot had the highest weed index (53.30%), followed by pendimethalin (34.3%), imazathapir (19.3%), and imazamox (16.2%).

Mundra *et al*. (2017) indicate application of sulfentrazone 360 g ha^{-1} have significant improvement in yield and further increase in its dose failed to record significant improvement in seed yield. It was established that weed control efficiency was ranging from 51.46 to 79.1 per cent under different treatments during the phase of crop growth. Residual effect of sulfentrazone at different doses as well as imazethapyr for weed control treatments was not found significant in influencing yield of wheat, mustard and gram.

Rawat *et al*. (2017) revealed that application of sulfentrazone will obtain higher values of growth and yield attributes namely branches per plant, CGR, pods per plant, seeds per pod and seed yield were influenced significantly with weed control treatments. Application of sulfentrazone 48 EC @ 360 a.i ha^{-1} resulted significantly higher seed yield and higher net returns and cost: benefit ratio and effectively controlled weed infestation and enhanced all growth, yield components and yield in soybean over check herbicide pendimethalin and weedy check.

Vijay *et al*. (2018) reported that Pre emergence of (PE) application of pendimethalin @ 2.5 l ha^{-1} at 20 DAS resulted in the lowest weed dry matter and maximum weed control efficiency followed by PE application of pendimethalin @ 2.5 l ha^{-1} followed by imazethapyr + imazamox @ 100 g ha^{-1} at 20 DAS. This treatment also recorded highest seed yield of soybean and also it was found to be economical with high B:C ratio.

Parmar *et al.* (2017) observed that hand weeding twice at 20 and 40 DAS was the most effective weed management and resulted in the highest weed control efficacy (96.27%) and low weed intensity with significantly higher seed yield (922.22 kg ha^{-1}).

Yadav *et al*. (2017) reveled that plot were comparatively clean since the first cohort of grass weeds was not allowed to germinate or grow due to the PRE application of pendimethalin.

Meena *et al.* (2018) carried out an experiment during *Kharif* 2016 and 2017 at Kota, Rajasthan. The results accrued over two years revealed that the application of herbicides significantly control the weeds during the critical period of crop-weed competition. The yield reduction due to weeds was 69.68 per cent. Among herbicidal treatments, the maximum weed control efficiency and highest yield was with premix formulation of Pendimethalin + Imazethpyr SL premix applied are equally effective to control the weeds in soybean.

Jadhav and Kashid (2019) found that post-emergence application of herbicide in conjunction with hand weeding at 30 DAS, recorded in the lowest amount of weed biomass (38.1 g m^{-2}), a higher weed control efficiency (62 %), a lower weed index (8.0), and maximum seed production and net returns in soybean.

Patel *et al.* (2019) reported that among the different weed control treatments, the higher WCE was found in plots were combination of weedicide application with manual weeding followed by single weedicide application had the highest WCE among the various weed control methods. Furthermore, hand weeding at 20 and 40 DAS twice in soybean has highest Weed control efficiency.

Daramola *et al.* (2020b) observed that compared to the untreated control, hoe weeding at 6 WAS in both years reduced total weed density by 43-69% and total weed biomass by 37-65%.

Meena *et al* (2020) results showed that all weed control treatments two hand weeding at 20 and 40 DAS recorded significantly lower weed density, weed dry weight, maximum weed control efficiency.

Nayak *et al*. (2000) reported that weed population and weed dry matter were lowest and weed-control efficiency was higher in weed-free treatment, followed by 2 hand-weedings and pendimethalin 5G @ 1.25 kg ha^{-1}. The highest seed yield was recorded with weed-free treatment which was at par with 2 hand weedings and pendimethalin 30 EC @ 1 kg ha^{-1}.

Kanatas *et al*. (2020) reported that weedy check treatment recorded the lowest weed control efficiency and hand weeding treatment yielded the best results in terms of weed control efficiency.

Rupareliya *et al*. (2020). found that combination of pre- and post-emergence herbicide and manual weeding led to improved weed control and reduced crop-weed competition during the crop's growth period. This resulted in a decrease in the number of weeds and dry weight. Additionally, the absence of weeds improved the availability of space, sunlight, moisture, and nutrients, which in turn enhanced water and nutrient intake. This, in turn, may have accelerated the photosynthetic rate and increased the availability of carbohydrates, leading to cell division.

Kumar *et al*. (2021) found that due to constant rainfall and high labor expenses, hand weeding at 20 and 40 DAS (twice) is ineffective. In recent years, there has been an increase in the usage of herbicides to suppress weed growth. Integration of herbicides with cultural weeding is a paying proposition in controlling weeds. However, to achieve the intended result, timely application of different weed control methods is necessary to achieve the desired target. Killing one or two flushes of weed before seeding a crop and immediate cultivation of the field after harvest to eliminate any weed has added advantage.

Tehulie *et al*. (2021) reported that both post-emergence herbicides effectively restricting weed development, which is augmented by hoeing during the critical stage of crop growth, which inhibits weed growth and results in higher seed and straw yields.

Arsenijevic *et al*. (2022) found that that out of all the herbicidal treatments, hand weeding had the lowest recorded weed biomass. This treatment proved to be significantly superior.

Charitha *et al.* (2022) found that weed management efficacy in groundnut is greater with the integration of pre-emergence application (PE) of diclosulam at 26 g ha^{-1} *fb* inter-cultivation at 20 DAS, while the next best options for higher WCE and pod yield were imazethapyr + pendimethalin (ready-mix) at 960 g/ha PE fb inter-cultivation at 20 DAS and sodium acifluorfen + clodinofop-propargyl 250 g ha^{-1} *fb* inter-cultivation at 40 DAS.

Meena *et al.* (2022b) concluded that when comparing weed free to weedy check, weed free had the lowest weed density and the highest weed control efficiency, while Pendimethalin as PE *fb* one hand weeding had the lowest weed index. Pendimethalin fb one hand weeding was applied to weeds at the 2-3 leaf stage.

Meena *et al.* (2022a) observed that two hand weeding at 20 and 40 days after sowing (DAS) resulted in the highest soybean seed production (1800 kg ha^{-1}) and the highest weed control efficiency (77.79%).

Gohil *et al.* (2022). Pendimethalin 750 g ha^{-1} as preemergence *fb* IC and HW at 30 DAS or pre-mix pendimethalin+imazethapyr 750 g ha^{-1} as preemergence *fb* IC and HW at 30 DAS were applied to effectively control weeds and increase chickpea seed yield and net return.

Gairola *et al.* (2023) affirmed that minimal weed density under the hand weeding treatment, emphasizing the elimination of all weed types during the weeding process.

Roy *et al.* (2023) demonstrated that the implementation of weed-free practices, which involved hand weeding twice between 20 and 40 days after sowing (DAS), pre-emergence and post-emergence applications, and weed control efficiency achieved the highest levels. Additionally, the use of herbicides resulted in significantly lower total weed density and biomass, as well as higher soybean yield and net returns.

2.5 Effect of weed management practices on succeeding crop

According to Deore *et al*. (2009) opined that the weed-free treatment created substantially greater stover production (2772 kg ha^{-1}) and grain yield (2336 kg ha^{-1}) among the weed control techniques. Another effective treatment for weed control during the early development stage was pendimethalin applied at 30 DAS at 0.5 kg kg ha^{-1} pre-emergence + HW + IC. After harvesting the kharif soybean, subsequent crops including sorghum, bajra, barley, and ragi can be sown safely. The treatment imazethapyr 75 g/ha post- emergence at 25 DAS +HW+IC 45 DAS) recorded the least no. of weeds m^{-1} and had no residual impact on those crops at 60 DAS.

Nalini *et al*. (2010) found that the preemergence application of pendimethalin (38.7%) at 2.0 kg ha^{-1} 3 day after sowing (DAS) + hand weeding (HW) on 45 DAS showed effective weed control in cotton without leaving any residues in the soil at the time of harvest and carryover problems to the succeeding crops, viz. pearl millet, cowpea and sunflower grown in sequence.

Sondhia *et al*. (2015) reveled herbicide residues are initially high in herbicide recommendations for weed suppression; however, they rapidly decline and are generally undetectable after a few days, weeks, or at harvest. The soil serves as an important buffer, influencing the persistence and fate of most herbicides in the environment. Herbicides may have a little deleterious influence on soil ecosystems. Herbicides have not been discovered at levels within the soil or food chain that would be cause for concern when used at approved doses. Furthermore, the tropical temperatures in India shortened the persistence and half-life of some herbicides. This might explain why the residue levels are so low. It may be inferred that low to moderate levels of herbicide contamination in plants and soil are rare in India.

Yadav and Bhullar (2014) reported the residual effects of pendimethalin, quizalofop, premix of imazethapyr + imazamox, applied to soybean, on the succeeding winter crops were determined through field bioassay at Ludhiana, Punjab. The results indicated that the herbicides applied to soybean did not show any significant effect on seedling emergence, plant height and dry matter accumulation of all the succeeding crops, *viz.* wheat, barley, spinach, pea, raya, canola and sugarbeet, indicating the safety of all the three herbicides, used alone or in sequence, for all the succeeding crops grown in rotation with soybean.

Zahana *et al.* (2018) investigated the residual effect of herbicides applied in strip tilled wheat on the succeeding crop i.e mungbean, jute and sunflower at through bioassay techniques. The results of study revealed that germination and crop growth; leaf chlorophyll and crop dry matters of these succeeding crops were not affected by any of the herbicide's residue applied in wheat. Shoot lengths of mungbean and sunflower were increased in the herbicide treated plots but root lengths of some herbicide treated plots were decreased at a negligible rate compare to the control one. Therefore, residual effect study claimed that use of the tested herbicides in wheat is safe for germination and growth of the succeeding crops.

2.6 Residual effect of herbicides

Arora and Tomar (2008a) reported that pendimethalin 1.5 to 0.75 kg ha^{-1} persisted in soil up to 75 days.

Patel *et al*. (2009) observed at harvest residue of imazethapyr was not found in soybean grains and straw, however residues of imazethapyr in soil at various treatments were found 0.0124 to 0.0121 μg/g.

Sondhia and Gopal (2009) noted that 18.6 % herbicides are responsible for residues above the maximum residue level mainly in rice and wheat, followed by soybean. However, 72% herbicides showed faster dissipation by various means only 9.3% herbicides are responsible for residues below the maximum residue limit which showed adverse toxicity to soil, succeeding crop and non-target organisms which includes soil micro flora and fauna.

Szmigielski *et al.* (2009) reported on the basis of high sulfentrazone bioavailability in soils of low organic matter and low clay and relatively long half-life reported for sulfentrazone (up to 302 d), there might be a risk of carry over injury associated with sulfentrazone. Thus, the re-cropping intervals recommended for sulfentrazone may be different for different soil types and different landscape positions within a field.

Janaki *et al*. (2012), reported that the quantity of herbicides used affected their initial deposition. Herbicides dissipated gradually and continuously over time, with first-order kinetics applied to all cases. Herbicide half-lives rose with application concentration, with atrazine, metolachlor, pendimethalin, pretilachlor, butachlor, and alachlor having the highest mean half-life. Metolachlor remained in the soil for a longer duration than other chloracetanilide herbicides. The study demonstrates that herbicide breakdown in soil is influenced by both the herbicide's intrinsic qualities and soil factors. Within the period of crop harvest more than 98 per cent of herbicides dissipated from the soil, except metolachlor and atrazine.

Sondhia *et al.* (2015) reported imazethapyr was applied at 100 g ha^{-1}, as a post emergence herbicide, the residues in the range from 0.006 to 0.018 μg/g was found in the soybean grains. However, in the soil, residues were found to be below 0.0010 μg/g to 0.0015 μg/g in one location. Less residues were found in soils as compared to plant samples. Based on this study a pre-harvest interval of 90-102 days is suggested for soybean crops after imazethapyr application.

Babu *et al*. (2015) revealed that the residue of imazethapyr persists in soil up to 60 days, there may be a chance for the bioaccumulation in plant through plant uptake. Hence, a pre harvest interval of 75 days must be allowed after the application of imazethapyr for weed control.

Deore and Patil (2016) observed his field experiment conducted at Junagadh, Gujarat, the biometric observation about germination percentage of succeeding crops *viz. Rabi* sorghum, bajra, barley and ragi was done after 10 days of sowing. Plant height and dry matter production data were recorded after 30 days of sowing. The results indicated no significant difference among the different treatments combinations consist of pendimethalin, quizalofopethyl and imazethapyr. The germination percentage, plant height and dry matter production were not affected by the application of different herbicides as well as fertilizers. These clearly indicates that the herbicides and fertilizers applied to soybean crop does not have any phytotoxic effect on the succeeding crops

Rani *et al*. (2022) investigated the residual effect of different herbicides applied in maize on succeeding greengram showed that using two hand weedings at 15 and 30 DAS resulted in lower density and dry weight of total weeds as well as higher yield attributes and yield. And at a par with atrazine 1.0 kg ha^{-1} as PE fb one HW at 30 DAS, atrazine 1.0 kg ha^{-1} as PE *fb* topramezone 30 g ha^{-1} as PoE, and atrazine 1.0 kg ha^{-1} as PE *fb* tembotrione 120 g ha^{-1} as PoE. The enzyme activity and microbial count in the soil at the time of the next greengram harvest were not statistically affected by herbicides applied to maize.

2.7 NPK depletion and uptake by weed and crop

Dhaker *et al*. (2015b) concluded that applying two hoeing and weedings and imazethapyr 100 g/ha+ HW at 40 DAS resulted in the highest seed production (1475 and 1395 kg/ha, respectively). Two HW significantly decreased weed growth and nutrient intake, improving crop nutrient uptake in soybeans and weeds.

Sharma *et al*. (2016) observed weeds removed the minimum amount of total nitrogen and phosphorus in the weed-free treatment, followed by pendimethalin + hand weeding at 30 DAS and two hand weeding at 15 and 30, while the weedy check removed the maximum nutrients. The amount of nitrogen and phosphorus uptake by crops and weeds may be attributed predominantly to their dry matter production.

Singh *et al*. (2017) reported that nutrient uptake is a numerical product of nutrient content and dry matter accumulation. Higher nutrient uptake might be due to less or no contribution of weeds in soybean nutrient removal. Weed suppression may be attributed to more root system proliferation and higher dry matter accumulation by individual plants due to better availability of resources to the crop for growth, resulting in higher yield.

Bhimwal *et al*. (2018) found that nutrient loss through uncontrolled weed growth throughout the crop season resulted in a loss of 137.86 kg N ha^{-1}, 21.29 kg

P_2O_5 ha^{-1}, 132.99 kg K2O ha^{-1} and 8.76 kg S ha^{-1}. Propaquizafop + Imazethapyr had the lowest mean total uptake of N, P, K, and S by weeds recorded, and it outscored other herbicide treatments substantially.

Dhakad *et al*. (2022) reported that two-hand weeding at 20 and 40 DAS was significantly superior in reducing weed dry matter and nutrient uptake by weeds at 30 and 60 DAS, which enhanced seed and straw yield of soybean, reduced NPK uptake by total weeds, and significantly improved nutrient uptake by soybean, resulting in higher seed yields.

Kumar *et. al*. (2022a) found that weed control through the integration of herbicides with cultural weeding is a paying proposition.

Monteiro and Santos (2022) reported weeds hinder the growth of crops by competing for resource utilisation for essential resources, resulting in significant losses in crop production.

Borje *et al*. (2023) revealed that minimum and significantly lower NPK uptake by weeds were noted in weed-free treatment. Among herbicidal treatments, diclosulam + hoeing at 20 DAS showed a significantly lower value of NPK uptake, which was found to be on par with the pendimethalin + hoeing at 20 reduced density of weeds results in significantly lower uptake of nutrients. Maximum and significantly higher NPK uptake by weeds were observed with treatment weedy check.

Vishwakarma *et al*. (2023) opined higher grain and straw yield results in higher nutrient uptake due to availability of proper space and light to crop because of increased weed control in herbicidal treatments during critical periods of crop growth. This may also be attributed to the impact of lower competition under herbicide-applied plots, which because of better weed suppression resulted in improved canopy development and increased nutrient uptake. An increase in nutrient uptake (NPK) also suggests that NUE was high under the given treatment due to reduced crop-weed competition and increased crop yield due to less weed population.

2.8 Bioassay Studies

Horowitz (1976) revealed that bioassay techniques used in herbicide studies are based on the response of chosen organisms, superior plants, or microorganisms, to the chemical. Various means of assessment are used: germination, weight or size of plant parts, modifications in physiological activities such as photosynthesis and transpiration, and typical symptoms. Dose response relations are affected by the age of the indicator plant and environmental conditions of growth. Results can be estimated visually or by objective measurements; for correct interpretation appropriate controls and standards must be included in each experiment.

Arora and Tomar (2008b) observed from an experiment conducted at during rabi to determine the persistence of pendimethalin in soil applied to eight different crops using bioassay technique. Maize was used as sensitive crop. Plant height, fresh weight and dry weight were significantly affected by pendimethalin up to 75 days after application (DAA) while effect of crops and the interaction were non-significant.

Szmigielski *et al.* (2008) reported that the bioassay was a better predictive tool for yield reduction than chemical analysis whereas in farm fields where history of other herbicide applications was not identified, bioassay and chemical analysis were similar in their agreement with visual injury symptoms (70.2% and 80.8% agreement, respectively).

2.9 Economic analysis on weed management

Venkatesha *et al*. (2008) observed that the weed-free check had the highest gross return, which was comparable to that of imazethapyr 75 and 100 g alone or with hand weeding, but the weedy plot had the lowest gross return among herbicidal treatments. The highest gross yields have been obtained with imazethapyr at 75 g/ha alone or with hand weeding. A similar pattern emerged when calculating both net and gross returns in soybean.

Nandini *et al*. (2016) reported application of imazethapyr as post emergence resulted in a higher B:C ratio (3.17) than other treatments followed by quizalofop ethyl (3.02).

Nagre *et al*. (2017) found that pendimethalin fb one-handed weeding and pendimethalin fb tank mix imazethapyr + propaquizafop have led to substantially reduced total weed count, weed dry matter, and weed index while improving WCE, herbicide efficiency index, crop resistance index, soybean grain, straw yield, net returns, and B:C ratio.

Rajkumari *et al.* (2017) revealed from the experiment conducted at Rajasthan College of Agriculture, Udaipur two hand weeding have a significantly higher in yield attributes with seed yield (21.30 q ha^{-1}) and return (₹ 23,242 ha^{-1}) with B:C ratio (1.73) over other treatments followed by imazethapyr (100 g ha^{-1}) with filled pods/ plant (45.84 seeds/pod (2.22), seed index (12.20 g), seed yield (18.86 q ha^{-1}), oil yield (3.87 q ha^{-1}), protein yield (7.69 q ha^{-1}), net return (₹ 23,231 ha^{-1}) and B:C ratio (2.50).

Ahirwar *et al.* (2018) revealed in his experiment two hand weeding (HW) at 20 and 45 DAS recorded maximum number of plants, dry matter accumulation of plants at harvest, number of branches, pods, seed index and yield with B:C ratio which was significantly higher over weedy check.

Binjha *et al*. (2022) opined that PoE herbicide was effective in reducing weed biomass, resulting in higher weed control efficiency during the initial crop growth stage, producing maximum soybean yield, and attained maximum net return and B:C ratio.

Ahirwar and Ahirwar (2023) revealed that the highest cost of cultivation was observed in 2 HW at 20 and 40 DAS, as compared to pendimethalin treatment + HW at 40 DAS. The highest gross return was obtained in the weed-free treatment, followed by two-time hand weeding at 20 and 40 DAS over the weedy check. The weed-free treatment produced the highest mean net return. The lowest B:C ratio of

1.43 was recorded in the weedy cheek, indicating that the weed population significantly influenced yield along with the monetary return.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

A field experiment entitled "Evaluation of herbicides for weed management in soybean (*Glycine max* L.) and its residual effect on succeeding linseed (*Linum usitatissimum*)" was carried out during the two consecutive seasons of *kharif* 2019 and *kharif* 2020 at Agronomy Experimental Farm, School of Agricultural Sciences (SAS), Medziphema campus, Nagaland University, to study the performances of herbicides for weed management in soybean and the residual effect of herbicides on succeeding linseed. The details of experimental technique followed, materials used, and research methodology adopted for treatment evaluation during the course of investigation to complete various studies in the field and laboratory are presented systematically and described in this chapter under appropriate headings.

3.1 General information

3.1.1 Site of experiment

The present experiment was conducted during the two consecutive years in the Experimental Research Farm, Department of Agronomy, School of Agricultural Sciences (SAS), Medziphema Campus, Nagaland University, during the *kharif* seasons of 2019 and 2020. The experimental site is located in the foothills of Nagaland with the geographical location 25°45'09.2 N latitude and 93°51'18.6 E longitude, with an altitude of 310 metres above mean sea level (msl).

3.1.2 Climate and weather conditions during the experiment period

The climate in Medziphema, Nagaland, is humid subtropical with dry winters. The district average minimum and maximum temperatures range from 9 to 24 °C and 23 to 33 °C, respectively. The monsoon season commences in June and lasts upto September. The wettest months are May, June and July, with annual rainfall averages ranging from 1800 mm to over 2500 mm.

Weekly meteorological data for the present investigation were recorded at ICAR Research Complex for NEH Region, Nagaland Centre, Jharnapani. Tables 3.1(a) and 3.1(b) exhibit these data, whereas Figures 3.2(a) and 3.2(b) illustrate them graphically.

Crop growth is the net result of interplay of diverse metabolic activities taking place in different parts of the plant during its growth and development. Variation in weather parameters were observed in both the years

During the first yield field trial, the highest monthly average temperature (35.10 °C) was observed in August, while February had the lowest monthly average temperature (7.60 °C). During the soybean and linseed research experiment, monthly average temperatures varied from 20.50 °C to 35.10 °C, with minimums ranging from 7.60 °C to 25.30 °C.

In 2019-2020, the highest average maximum temperature was recorded in August (35.10°C), while the lowest monthly mean minimum temperature (20.50°C) was seen in January. During the research period, the monthly average maximum temperature varied from 35.10 °C to 20.50 °C, while the minimum temperature was 25.30 °C to 7.60 °C.

During the second year of the field experiment, the highest monthly average temperature was observed in August (34.70 °C) and the lowest monthly minimum average temperature (7.20 °C) in December. During the soybean and linseed research period, the maximum monthly average temperature varied from 34.7°C to 22.80°C, while the minimum monthly average temperature was between 25.30°C and 7.2°C.

In 2020-2021, the highest average maximum temperature was recorded in August (34.70 °C) and the lowest monthly mean minimum temperature (22.80 °C) in January. During the research period, the highest monthly average temperature ranged from 34.70 °C to 7.2 °C, while the lowest monthly average temperature ranged from 22.80 °C to 25.30 °C.

The cumulative rainfall reported throughout the study period of the experiment was 972.20 mm and 572.6 mm in the years 2019, 2020, respectively (Table 3.1). However, in the 2019-2020 season, the highest rainfall was recorded in October (152.90 mm) and the lowest in January (0.4 mm). Meanwhile, in 2020-21, the maximum rainfall occurs in October (103.90 mm) and the lowest in January (0.4 mm) in the years 2020-2021.

Regarding cumulative relative humidity (RH), during the first year of 2019-2021, the highest monthly relative humidity was recorded in November (98 %), while the lowest monthly mean minimum relative humidity was in February (45%). However, during the second year of 2020-2021, the highest monthly mean maximum relative humidity was in November (98%), and the lowest monthly mean minimum relative humidity was in February (37 %).

About cumulative relative humidity (RH), in the first year the maximum monthly relative humidity was recorded in November (98%), while the lowest monthly mean minimum relative humidity was in February (45%). However, in the second year of 2020, the greatest monthly mean maximum relative humidity was in November (98%), while the lowest monthly mean minimum relative humidity was in February (37%).

During 2019-2020, the minimum and maximum mean weekly sunshine duration varied from 0.2 to 8.3 hours, with an average of 4.25 hours, and between 1.9 and 8.3 hours, with an average of 5.10 hours, during 2020-2021.

3.1. 3 Previous cropping history of the experimental field

The previous crops cultivated grown in the experimental field (Table 3.2) were as follows.

Table 3.1(a) Mean weekly meteorological data during the experimental period (2019-20)

Week No.	Temperature (Max)	Temperature (Min)	Relative humidity (Max)	Relative humidity (Min)	Rainfall (mm)	Sunshine (hours)
28	30.8	24.9	94	78	34.1	0.2
29	35.0	24.7	92	61	57.4	7.1
30	33.5	24.5	93	70	111.5	3.1
31	33.1	24.8	95	72	29.1	3.7
32	35.1	25.3	92	68	42.5	5.8
33	33.8	24.5	92	74	121.6	3.9
34	34.0	25.1	91	72	24.5	5.0
35	33.8	24.7	93	75	64.6	5.1
36	34.0	25.1	94	72	21.2	5.2
37	33.1	24.7	94	73	16.3	3.1
38	33.9	23.3	92	66	37.3	5.2
39	29.6	22.5	95	79	94.6	2.2
40	31.0	22.6	95	77	22.1	5.9
41	31.2	23.2	95	69	50.8	6.4
42	32.5	21.6	94	65	19.0	7.6
43	26.5	20.1	96	81	152.9	2.9
44	30.7	19.2	97	69	0.0	8.3
45	28.7	19.6	97	76	34.9	4.2
46	29.0	16.2	97	59	18.0	8.0
47	27.8	13.3	98	58	0.0	7.6
48	27.9	13.5	98	63	0.0	7.0
49	24.9	11.4	97	60	0.0	7.1
50	24.8	10.7	97	62	0.0	5.9
51	22.6	10.9	97	67	0.0	5.1
52	21.7	8.3	97	59	0.9	6.2
1	20.5	10.9	97	73	17.3	3.2
2	22.3	9.6	97	62	0.0	6.0
3	25.1	10.4	97	56	0.4	5.5
4	21.5	7.6	97	52	0.0	5.9
5	22.2	9.6	97	55	0.8	4.2
6	23.8	10.0	96	49	0.0	5.9
7	25.7	11.6	97	45	0.4	4.4
8	26.6	12.1	97	55	0.0	5.1

Source: ICAR Research Centre for NEH Region, Nagaland Centre, Medziphema

Table 3.1(b) Mean weekly meteorological data during the experimental period (2020-21)

Week No.	Temperature		Relative humidity		Rainfall (mm)	Sunshine (hours)
	(Max)	(Min)	(Max)	(Min)		
28	32.9	24.8	93	71	29.7	1.9
29	32.3	24.6	93	72	18.5	2.8
30	32.0	23.9	93	76	71.4	2.2
31	33.6	25.3	94	70	3.5	4.8
32	34.7	25.3	92	71	10.8	4.5
33	33.6	25.2	92	67	31.4	3.0
34	32.4	24.4	96	74	32.3	4.0
35	33.1	24.7	93	71	42.9	4.8
36	33.8	24.3	94	64	10.7	7.3
37	33.3	24.3	95	72	58.5	4.5
38	33.2	24.5	96	76	17.3	3.6
39	31.3	24.1	95	80	31.3	3.4
40	32.5	23.5	95	80	103.9	4.6
41	32.2	23.4	95	71	2.5	7.0
42	32.4	23.6	94	64	1.1	6.2
43	28.6	22.0	97	80	68.2	3.6
44	30.1	22.5	96	74	34.8	4.1
45	29.3	17.7	97	61	0.4	7.4
46	29.0	15.2	98	60	0.0	8.1
47	26.2	14.0	97	56	0.0	5.7
48	26.3	12.1	97	55	0.0	7.2
49	26.1	11.7	97	54	0.0	7.3
50	24.7	11.4	97	58	0.0	6.5
51	23.3	9.1	97	54	0.0	6.6
52	23.8	7.2	96	45	0.0	7.5
1	24.9	7.4	96	43	0.0	8.1
2	24.5	9.6	96	50	0.0	5.6
3	22.8	9.6	97	63	3.4	4.2
4	23.0	8.8	97	49	0.0	6.5
5	24.7	8.1	96	45	0.0	7.6
6	26.3	7.7	95	37	0.0	8.1
7	27.4	9.0	94	39	0.0	8.3
8	29.2	11.3	93	37	0.0	7.4

Source: ICAR Research Centre for NEH Region, Nagaland Centre, Medziphema

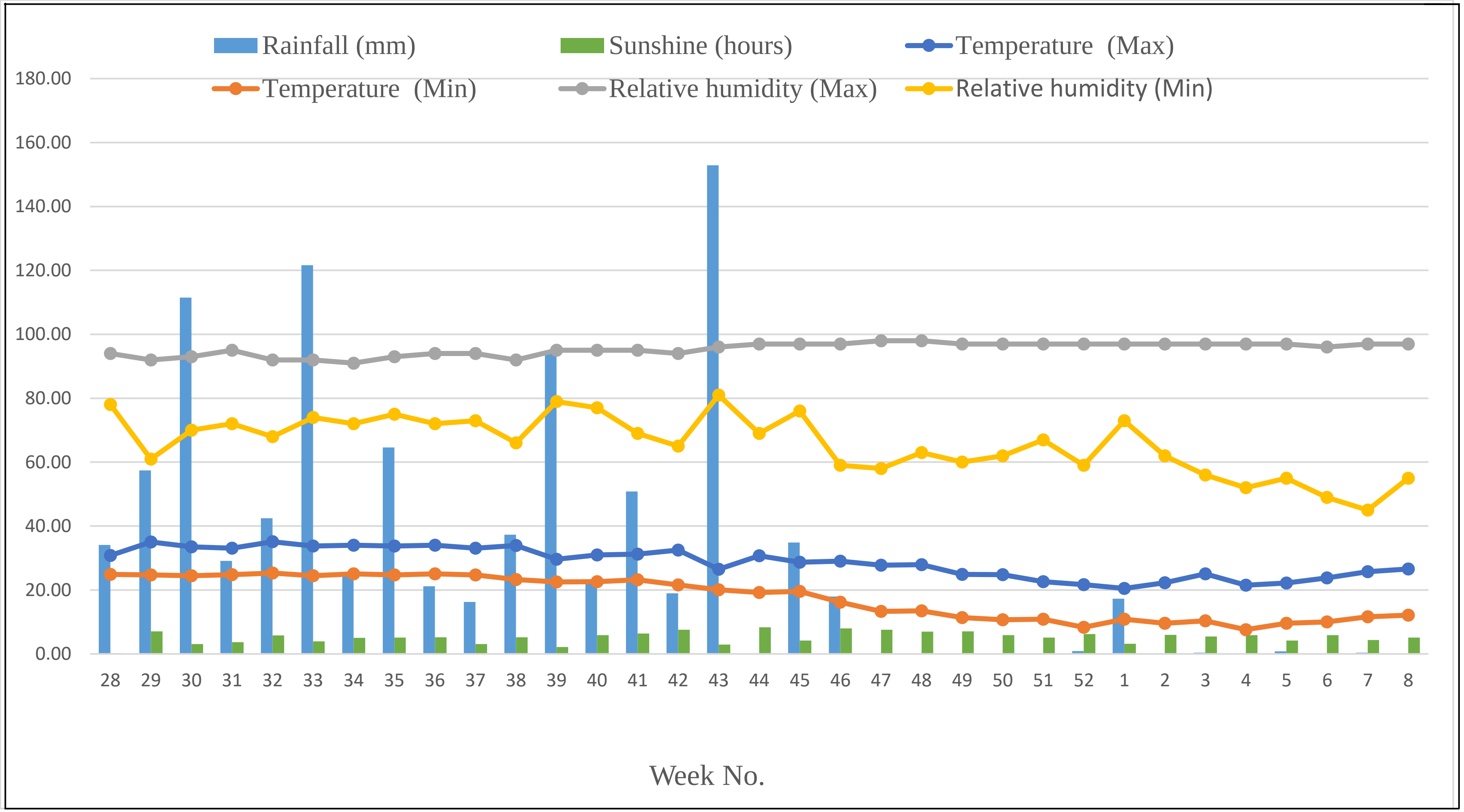


Fig 3.1 (a) Meteorological data during the cropping season (2019-20)

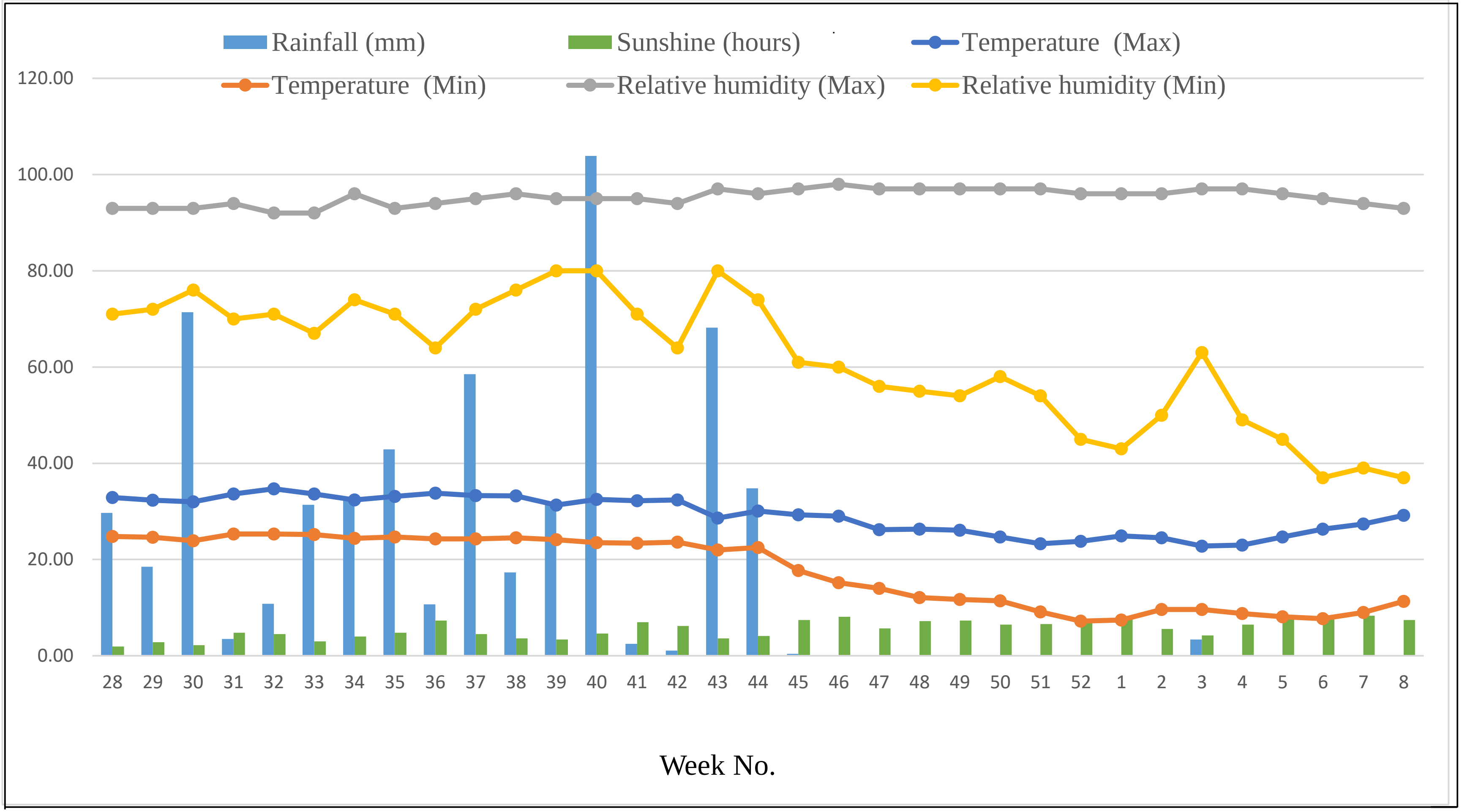


Fig 3.1 (b) Meteorological data during the cropping season (2020-21)

Table 3.2 Previous cropping history of the experimental field

Year	*Crops grown*	
	Kharif	***Rabi***
2014-2015	Fallow	Fallow
2016-2017	Fallow	Fallow
2017-2018	Fallow	Fallow
2018-2019	Fallow	Fallow
2019-2020	Present soybean experiment	

3.1.4 Soil condition

The soil of the experimental plot was categorized as sandy loam and well-drained. To determine the soil's physiochemical properties before and after the crop harvest, samples were collected from five randomly selected sites in the field at depths ranging from 0 to 15 cm, using a screw-type soil auger. Then, all the soil specimens were combined to form a composite. The composite soil sample was pulverised into powder with a mortar and pestle. The powdered material was screened through a 2 mm mesh before being tested in the laboratory following standard procedures. Table 3.3 summarises the soil analysis findings.

Table 3.3(a) Initial physico-chemical properties of soil

Characteristics	**Method followed**	**2019**	**2020**
A. Physical properties			
Sand (%)	International pipette method piper (piper (1950)	51.20	51.22
Silt (%)		25.55	25.56
Clay (%)		23.25	23.22
Soil texture class		Sandy clay loam	Sandy clay loam
Bulk density (mg m^3)	Tripathi, 2020	1.18	1.17

Table 3.3(b) Initial physico-chemical properties of soil

Characteristics	Method followed	2019		2020	
		Content	Interference	Content	Interference
B. Chemical properties					
pH	Digital pH meter (Jackson, 1973)	4.80	Strongly acidic	4.88	Strongly acidic
Electrical conductivity (EC)	Solubridge methods (Jackson, 1973)	0.20	Normal	0.21	Normal
Organic carbon (%)	Titrimetric determination (Walkley & Black, 1934)	1.40	High	1.46	High
Available Nitrogen (kg ha^{-1})	Alkaline potassium permanganate method (Subbiah and Asija, 1956)	358.24	Medium	354.87	Medium
Available Phosphorus (kg ha^{-1})	Bray's No. 1 method (Bray and Kurtz, 1945	18.46	Medium	19.49	Medium
Available Potassium (kg ha^{-1})	Neutral normal ammonium acetate method (Hanway and Heidal, 1952)	224.37	Medium	219.52	Medium

3.2 Experimental Details

3.2.1 Design and Layout

The field experiment was conducted for two years during *kharif* 2019 and 2020 at the Agronomy Farm of SAS, Nagaland University, Medziphema, Nagaland, where soybean *var*. JS 97-52 was sown according to the recommended package of practices, and fertiliser dose of 25-60-40 kg ha^{-1} NPK (in the form of urea, SSP, and MOP) was applied along with FYM @ 10 t ha^{-1} as the general dose for all plots irrespective of treatments. Without altering the layout, successive residual crops, linseed *var*. Shekhar were planted to investigate the residual effect of herbicides administrated to soybeans in the experimental field. The plan of layout is depicted in Fig. 3.4.

Details of the experiment are as follows

1	Experimental design	Randomised block design		
2	Crop	Soybean		
3	Variety	JS 97-52		
4	Replication	3		
5	Treatment	8		
6	Total no. of plot	24		
7	Plot size	Gross plot	:	5 m X 4 m = 20 m^2
		Net plot	:	4 m X 3 m = 12 m^2
8	Distances between replication	1.5 m		
9	Distances between plot	1 m		
10	Total experimental area	702 m^2		
11	Spacing	45 cm x 10 cm		
12	Recommended seed rate	65 kg ha^{-1}		
13	Sequential crop	Linseed (Shekar)		
14	Recommended doses of fertilizer	25-60-40 kg NPK ha^{-1}		
15	FYM	10 t ha^{-1}		

3.2.2 Treatment details

The experimental treatments consist of eight weed management methods, and their associated symbols are displayed below.

	Treatments	**Symbols**
Integrated weed management		
1	Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – Pre-emergence	T_1
2	Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS	T_2
3	Imazethapyr 10 SL @ 100 g a.i. – Post emergence, 20 DAS	T_3
4	Imazethapyr 10 SL @ 100 g a.i. (10 DAS) early post emergence – *fb* IC at 30 DAS	T_4
5	Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} – Post emergence, 20 DAS	T_5
6	Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} early post emergence – *fb* IC at 30 DAS	T_6
7	IC at 20 DAS *fb* hand weeding at 40 DAS	T_7
8	Unweeded (control)	T_8

fb – followed by *IC– inter cultivation* *DAS– days after sowing*

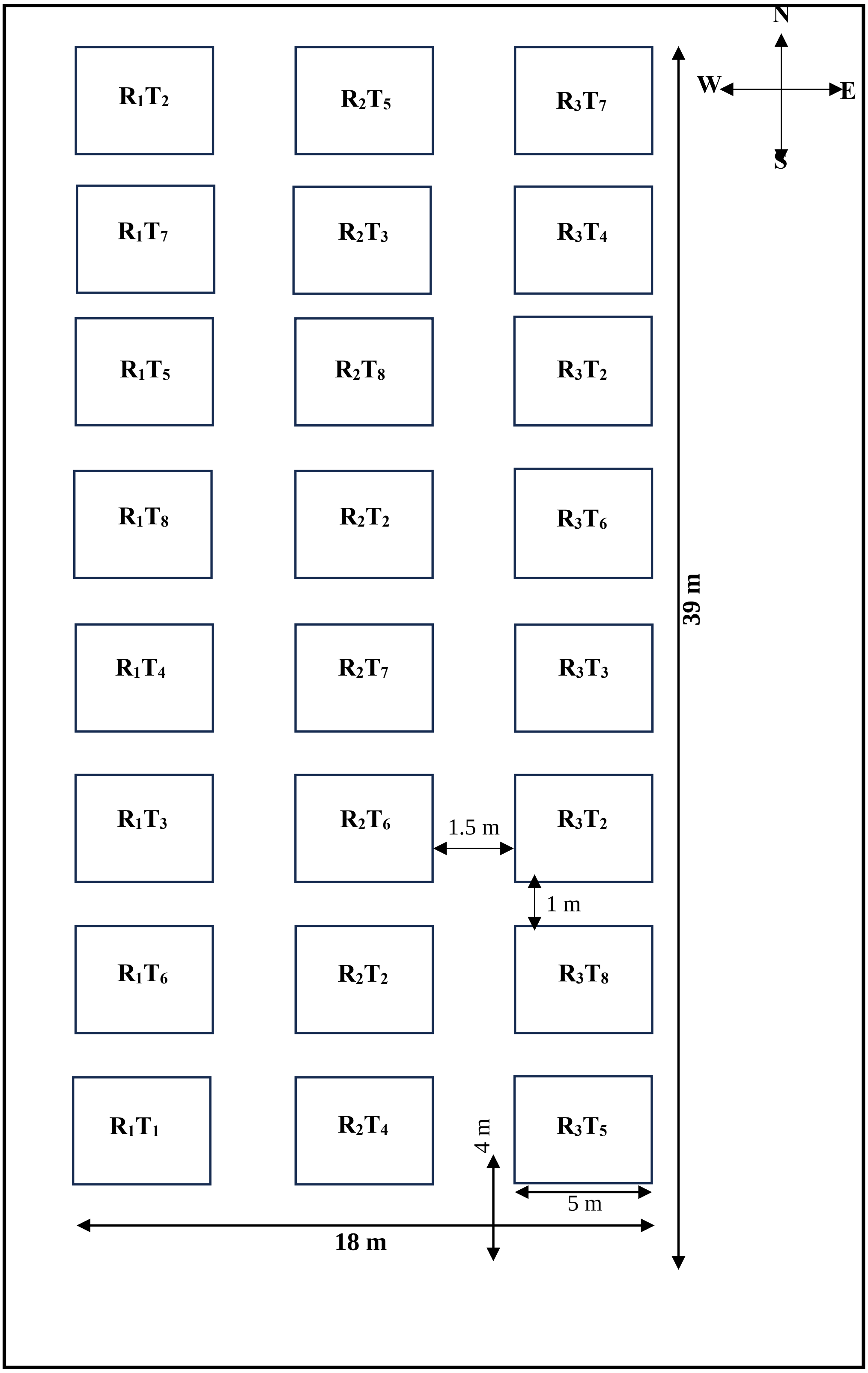
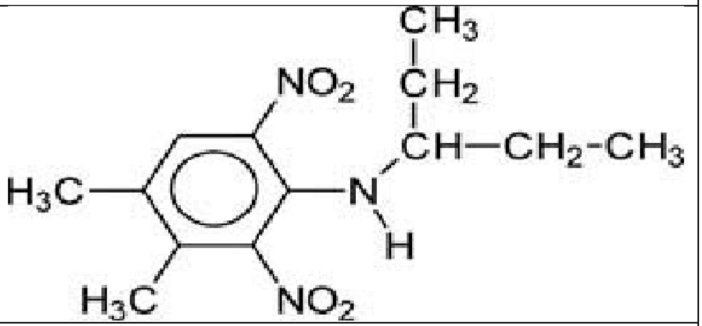


Fig. 3.2 Layout plan of experiment

3.2.3 Properties of herbicides use

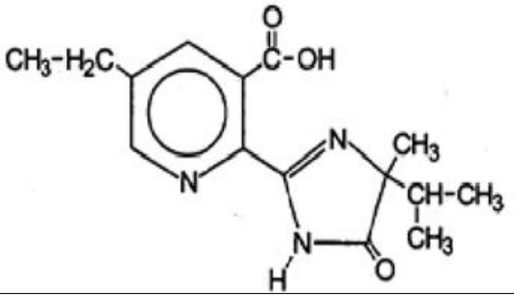
a. Pendimethalin

Common name	:	Pendimethalin
Trade name	:	Stomp
Chemical formula	:	N-(1-ethylpropyl) -3, 4-dimethyl-2, 6-dinitrobenzenamine
Empirical formula	:	$C_{13}H_{19}N_3O_4$
Formulation	:	Emulsifiable concentration (EC)
Chemical group	:	Dinitroanilines
Chemical structure	:	
Active ingredient	:	30 % EC
Molecular weight	:	281.31 g mol^{-1}
Melting point	:	47-58°C
Recommended dose	:	1 kg a.i. ha^{-1}
Application time	:	Pre or Early post Emergence
Type of weed control	:	Annual grass and broad-leaf weeds
Selectivity	:	Selective

Mode of action:

Pendimethalin acts as both as pre-emergence and early post emergence. Pendimethalin controls weed by inhibiting microtubule formation in cells. This causes interruption of cell division and elongation in susceptible species of weeds. It controlled a wide range of grasses and small seeded broad leaves weeds from emerging, during the crucial development phase of the crop.

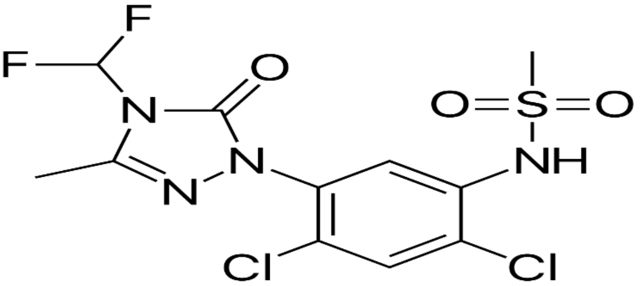
b. Imazethapyr

Common name	:	Imazethapyr
Trade name	:	Pursuit
Chemical formula	:	5-ethly-2 [(RS)-4-methyl-5-oxoo-2 imidazolin-2-yl] nicotine acid
Empirical formula	:	$C_{15}H_{19}N_3O_3$
Formulation	:	Ammonium Sulphate
Chemical group	:	Imidazolinones
Chemical structure	:	
Active ingredient	:	10 % SL
Molecular weight	:	289.3 g mol^{-1}
Melting point	:	169-173 ^0C
Recommended dose	:	100 g a.i. ha^{-1}
Application time	:	Pre-plant, pre-emergence, post-emergence
Type of weed control	:	broad leaf weeds, annual grasses
Selectivity	:	Selective

Mode of action:

It is absorbed by foliage and translocated through the xylem, phloem and accumulate in the meristametic regions. So, it controls the entire weed plant including the root rhizome. Inhibits acetolactate synthase (ALS), also called acetohydroxy acid iso leucine, leucine and valine. It will not harm the succeeding crops because it has short soil persistence. It controls both emerged and multiple flushes of shallow germinating weeds.

c. Sulfentrazone

Common name	:	Sulfentrazone
Trade name	:	Authority
Chemical formula	:	N-{2,4-Dichloro-5-[4-(difluoromethyl)-3-methyl-5-oxo-4,5-dihydro-1H-1,2,4-triazol-1-l] phenyl} methanesulfonamide
Empirical formula	:	$C_{11}H_{10}Cl_2F_2N_4O_3S$
Formulation	:	Ammonium Sulphate
Chemical group	:	Aryl triazolinone
Chemical structure	:	
Active ingredient	:	SULFENTRAZONE 4L
Molecular weight	:	378.2 g mol^{-1}
Melting point	:	121-123°C
Recommended dose	:	152 - 278 g a.i. ha^{-1}
Application time	:	Pre-plant, pre-emergence, post-emergence
Type of weed control	:	broad leaf weeds, sedge
Selectivity	:	Selective

Mode of action:

Sulfentrazone control weeds by disrupting membranes and inhibits photosynthesis in plants. It is commonly called PPO inhibition. Sulfentrazone is received in the plants through the roots of the plants. As the plants come out of the soil, they die after exposure to light. It also works of foliar contact causing rapid desiccation.

3.2.4 Characteristics of Variety

Soybean *var*. JS 97-52:

Soybean [*Glycine max* (L.) Merr,] variety JS 97-52 has been released by Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, from a cross between PK 327 x L129. It has a wide adaptable, high-yielding, and multiple resistant variety. Plants are marked with purple pigmentation and purple flowers. Its maturity period is 98-102 days, categorized as medium duration. Seeds are greenish yellow, lustrous with blackish hilum. It possesses excellent germinability, field emergence, and longevity during storage. The yield potential of this variety is 25-30 q ha^{-1}. It has been found resistant to YMV, root rot, bacterial pustules, charcoal rot, Cercospora leaf spot, and target leaf spot and rated as resistant high yielding on the basis of reaction to disease complex. Similarly, it has been rated as resistant and high-yielding against insect pests on the basis of the tolerance shown against stem-fly, girdle beetle, and defoliators. The seeds were obtained from the All India Coordinated Research Project on Soybean, SAS, Nagaland University, Sub Center – Medziphema.

Linseed *var*. Shekar

Linseed (*Linum usitatissimum* L.) variety Shekhar was evolved at Chandra Shekhar Azad University of Agriculture and Technology (CSAUAT), Kanpur. It contains 40% oil and matures in about 135–140 days. Variety is resistant to rust and wilt, having a yield potential of 15-17 q ha^{-1} and 9.2 q ha^{-1} under irrigated and rainfed conditions, respectively. The seeds were procured from the All India Coordinated Research Project on Linseed (AICRP-Sesame) SAS, Nagaland University, Sub Center – Medziphema.

3.3 Cultural Operation

The calendar of cultural operations carried out during the course of experimentation is given in Table 3.4.

3.3.1 Field preparation

The experimental fields were ploughed with a tractor-drawn mouldboard plough during the last week of June and once with a rotovator to get fine tilth. All the stubbles were removed, the field was levelled, and plots were laid out with beds and channels according to the experimental field plan and design.

3.3.2 Manures and fertilizers

Farmyard manure at the rate of 10.0 t ha^{-1} was applied uniformly over the field before last ploughing. The experimental plots were fertilised as per recommendation. The recommended dose of NPK at 25-60-40 kg ha^{-1} in the form of urea, single superphosphate, and muriate of potash was applied to all plots uniformly in lines and incorporated at the time of sowing. The entire dose of NPK was applied as basal.

3.3.3 Seeds and sowing

Soybean seeds were treated with Bavistin @ 2 g kg^{-1} of seeds, followed by inoculation with Rhizobium japonicum of soybeans @ 5 g kg^{-1} seeds before sowing to protect the crop from soil and seed borne diseases. The seed rate adopted for the experiment was 65 kg ha^{-1}. The crop was shown manually on (16/07/2019 and 17/07/2020) an open furrow in lines by dibbling two soybean seeds per hole at a depth of 3-5 cm along the rows with a spacing of 45 cm between the row-to-row and 10 cm plant to plant distance in each plot. Linseed was shown (25/10/2019 and 29/10/2020) immediately after the harvesting of soybean.

Table 3.4 Details of field operations carried out during experimentation

Sl. No.	**Field operations**	**Date**	
		2019	**2020**
1	Land preparation	26/06/2019	29/06/2020
a	Primary tillage- harrowing with cultivator	28/06/2019	30/06/2020
b	Secondary tillage- harrowing with cultivator	08/07/2019	09/07/2020
c	Layout of the experiment	12/07/2019	10/07/2020
2	Application of fertilizers	16/07/2019	17/07/2020
3	Seed treatments and sowing	16/07/2019	17/07/2020
4	Application of herbicides as pre-emergence	17/07/2019	18/07/2020
5	Gap filling and thinning	22/07/2019 26/07/2019	23/07/2020 27/07/2020

6	Application of herbicides as early post-emergence	26/07/2019 05/07/2019	07/07/2020 28/07/2020
7	Inter cultivation	05/07/2019 15/08/2019	07/08/2020 17/08/2020
8	Hand weeding	25/08/2019	27/08/2020
9	Harvesting	23/10/2019	27/10/2020
10	Threshing and winnowing	24/10/2019 till 01/11/2019	29/10/2020 till 03/11/2020
11	Sowing of succeeding seed	25/10/2019	29/10/2020
12	Harvesting of succeeding crop	22/02/2020	26/02/2021
13	Threshing and winnowing of succeeding crop	25/02/2020 till 30/02/2020	29/02/2021 till 05/03/2021

3.3.4 Gap-filling and thinning

After six days of sowing, germination of soybean was completed under each plot. To ensure a uniform plant population in all plots, gaps in the field were filled by reseeding with fresh treated seeds on the seventh day after first seeding. Similarly, when young germinated seedlings were overcrowded, additional seedlings were thinned at 10 DAS to maintain a heterogenous intra-row plant population nearly 10 cm apart. Only thin and weak seedlings were uprooted for the thinning of crowded plants without causing harm to other nearby plants.

3.3.5 Pest and disease

No serious pest and diseases were observed during the period of experimentation.

3.3.6 Weed management treatments

3.3.6.1 Unweeded control

In the unweeded control plot, weeds were permitted to grow without any weed management throughout crop growth and development.

3.3.6.2 Application of herbicides

The doses of different herbicides were determined as per treatment according to their active ingredient present in the commercial products. For spraying the herbicides, a spray solution was prepared by mixing the required quantity of herbicide(s) (pendimethalin, imazethapyr, and sulfentrazone) as per the herbicidal treatments in water @ 500 liters ha^{-1}. The spray solution for individual plots was prepared separately. After completing the spraying of one herbicide in the respective plots in all three replications, the sprayer was washed thoroughly, including the flat fan nozzle, by detergent and rinsed several times with fresh water, before being used for another treatment. A knapsack sprayer with a flat fan nozzle was used for the spraying of herbicidal treatments. Uniform pressure was maintained to pump out nearly equal quantities of the herbicide uniformly as a fine mist during the course of spray in each plot.

Different applications of herbicides were performed as per the treatment in all the experiments. Pre emergence application was done at 1 DAS, post emergence application was done at 20 DAS and early post emergence application was done at 20 DAS followed by interculture at 30 DAS during the experiment.

3.3.6.3 Interculture and hand weeding hand hoeing

Interculture and hand weeding were done manually with the help of *Khurpi*, and interculture was performed at 30 DAS according to the treatment combination with weedicide. Another treatment, interculture and hand weeding was carried out at 20 DAS and 40 DAS to keep the crop free of weeds throughout the critical phase of crop-weed competition.

3.3.7 Water management

Generally, during *kharif* season, no irrigation is required for the soybean crop from sowing to harvesting. Meanwhile, adequate drainage facilities were also provided by making drainage channels between plots along the slope of the experimental field to drain excess water from the experimental field.

3.3.8 Harvesting, threshing and winnowing

The crop was harvested at maturity on (23/10/2019 and 27/10/2020), when the soybean plants' foliage turned yellowish brown to brown in colour and leaves started shedding. To avoid the border impact, two rows from each side and 0.5 m at both ends of the rows were harvested and collected separately, thereby leaving a net plot size of 12 square meters. Then harvesting of crops from the net plot area was done plot wise separately with the help of sickles. The harvested plants of each plot were tied into bundles, tagged with a luggage label for demarcation, sundried, and weighed for recording biological yield. The produce was allowed to sundry in respective plots.

After sun drying, the produce was weighed plot-wise by using a spring balance. Then, threshing was done manually by beating up the produce with sticks for each plot separately (24/10/2019 and 29/10/2020). The threshed produce of each plot consisted of seeds and chaffy materials. The chaffy materials were removed, and the clean seed of each plot was separated by winnowing with a hand fan *(supa)* manually. The yield of the sample plants taken for post-harvest studies was also included in the yield of each plot, respectively. The weight of clean seed obtained from each plot was taken with the help of double pan balance.

3.3.9 Succeeding crops

To study the residual effect of herbicides applied to soybean, the succeeding crop linseed *var* Shekar were raised without disturbing the layout of experimental field after the harvest of soybean.

3.4 Sampling technique

Weed count was recorded by placing four quadrates of size 0.5 m × 0.5 m in each plot and weeds falling within the frames of the quadrate were counted and the mean values were expressed in number m^{-2}. The density of grasses, sedges, broad leaved weed and total weed count were recorded at 20, 40, 60 DAS and at harvest. The weeds falling within the frames of the quadrates were collected, categorised into grasses, sedges and broad-leaved weeds and washed free of soil. The collected weeds were first shade dried and dried in hot-air oven at 80 ^{0}C for 72 hrs. The dry weight of grasses, sedges and broad-leaved weeds were recorded separately at 20, 40, 60 DAS and at harvest. The individual dry weight was summed to arrive total weed dry weight.

3.5 Observations on weed

3.5.1 Weed flora of the experimental field

To account for the general weed flora of the experimental field, species wise weeds in the unweeded control plot were recorded at the period of maximum appearance of weeds (20 DAS). The weed flora of the experimental site was recorded species wise. The original values were subjected to square root transformation with the help of the formula $\sqrt{x+0.5}$, where x is the actual weed count.

3.5.2 Species wise weed counts (no. m^{-2})

The weed count was recorded species wise using 0.5 m × 0.5 m quadrate from four randomly fixed places in each plot and the weeds falling within the frames of the quadrate were counted. The weed counts of grasses, sedges, broadleaved weeds and the total weeds count were recorded at 20, 40, 60 days after sowing and at harvest stage. It is expressed in number m^{-2}. The original values were subjected to square root transformation with the help of the formula $\sqrt{x+0.5}$, where x is the actual weed count.

3.5.3 Weed dry weight (g m^{-2})

The dry weight of weed was recorded at 20, 40, 60 days after sowing and at harvest stage by taking samples of weeds from an area of 0.25 m^{-2} selected at random at two spots in each of the plots. The collected weeds were washed, sundried, and oven-dried at 70 ^{0}C for 48 hrs. The constant weights obtained and the original data were subjected to square root transformation $\sqrt{x+0.5}$, and analysed statistically.

3.5.4 Weed control efficiency (%)

Weed control efficiency was calculated at 20, 40, 60 DAS and at harvest on the basis of reduction in dry matter production of weeds in treated plots in comparison with weedy check and expressed in percentage as suggested by Mani *et al.* (1973). It is worked out by using weed population present in control and treated plots.

$$\text{WCE (\%)} = \frac{\text{Weed dry wt.in unweed plot} - \text{Weed dry wt.in treated plot}}{\text{Weed dry wt.in unweed plot}} \times 100$$

3.5.5 Weed index (%)

It is an index expressing the reduction in yield due to presence of weeds in comparison with weed free situation. It was expressed in per cent and calculated by using the formula given below (Gill and Vijaya Kumar, 1969).

$$\text{WI} = \frac{\text{Yield of crop in weed free plot} - \text{Yield of crop in treatment plot}}{\text{Yield of crop in weed free plo}} \times 100$$

3.6 Observation on crop

3.6.1 Growth attributes

Five plants were selected randomly from each plot and tagged to record the growth attributes at different stages of crop growth (30, 60, 90 DAS and at harvest). However, for dry matter weight of the plant five plants were randomly selected from the sampling rows at different growth stages.

3.6.1.1 Plant population (linseed)

The plant population of crop plants was recorded at 30 DAS and just before harvest, from one meter row length in 4 rows randomly in each plot and then averaged out. After this plant population per meter square was determined for each plot.

3.6.1.2 Plant height (cm)

Plant height from the five tagged plants from the middle rows was recorded at 30, 60 days after sowing (DAS) and at harvest. Plant height was measured by linear scale from base of the stem to the terminal apex. The mean height from the selected plants was taken as the score for each plot.

For the linseed, plant height was measured in cm from the ground level to the top at 30 DAS, average plant height was calculated for each of the treatments.

3.6.1.3 Number of branches plant^{-1}

The number of branches per plant of five (5) tagged plants was counted at 30, 60 days after sowing (DAS) and at harvest. The values were averaged for each plot.

3.6.1.4 Dry weight of plant (g plant^{-1})

The randomly five (5) plants from each plot were carefully uprooted. The uprooted samples were kept separately in paper bags after removing the root portion; the samples were sun-dried and oven-dried at 60 ^{0}C for 48 hours. After 48 hours, each sample attains a constant dry weight. Each sample was weighed, and dry matter accumulation was recorded at 30, 60 DAS, and at the harvest stage.

For the linseed, the plant's dry weight was taken at 60 DAS, and then the sample plants were sun-dried and later dried in a hot air oven for about 48 hours at 60 ^{0}C, each sample was weighed, and dry matter accumulation was recorded.

3.6.1.5 Number, fresh and dry weight of root nodules

Randomly selected five (5) plants were removed along with the soil up to the effective root zone from each plot with the help of a fork and *khurpi* and then dipped in water for separation of nodules from soil and washed gently with the help of a sieve to avoid washing over of nodules. A number of nodules were recorded at the most active stage at 30 DAS and 60 DAS. The nodules collected are then taken for fresh weight and later shade dry and further dried in an oven at 60 ^{0}C for 48 hours for nodules dry weight by an electronic digital balance, and the average dry weight of nodules plant^{-1} was worked out and recorded.

3.6.1.6 Leaf area Index (LAI)

The leaf area of leaves from five selected plants of each plot drawn for biomass observation were used for measuring leaf area with the digital leaf area meter. The LAI was worked out using the formula (Johnson, 1967). The LAI of the five (5) tagged plants were taken at 30 and 60 DAS.

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

3.6.1.7 Crop growth rate (CGR)

Crop growth rate (CGR) is the daily increment of biomass per unit ground area per unit time which represent the rate of dry matter production and it was worked out at 30-60 DAS and 60-90 DAS using the dry matter accumulation of plants by adopting the formula given by Watson (1958).

$$\text{CGR} = \frac{W_2 - W_1}{P(t_2 - t_1)} \quad \text{g m}^2 \text{ day}^{-1}$$

Where,

CGR= Crop growth rate

W_2 and W_1 = Whole plant dry weight (g) at stages of t_2 and t_1, respectively

t_2-t_1 = Time intervals in days

P = Land area occupied by the plants (m^2)

3.6.1.8 Relative growth rate (RGR)

This parameter indicates rate of growth per unit dry matter. The unit of RGR is g g^{-1} day^{-1}. The relative growth rate was computed at 30-60 DAS and 60-90 DAS using the dry matter accumulation of plant and calculated by using the formula given by Radford (1967).

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \text{ g g}^{-1} \text{ day}^{-1}$$

Where,

RGR= Relative growth rate

W_2-W_1=Dry matter accumulation at definite time intervals
t_2-t_1= Time intervals in days

3.6.1.9 Net assimilation rate (NAR)

The term, NAR was used by Williams (1946). NAR is defined as dry matter increment per unit leaf area or per unit leaf dry weight per unit of time. The NAR is a measure of the average photosynthetic efficiency of leaves in a crop community. NAR is expressed as the grams of dry weight increase per unit dry weight or area per unit time (g m^{-2} day^{-1}).

$$\text{NAR} = \frac{(W_2 - W_1) \text{x} (\log_e L_2 - \log_e L_1)}{(t_2 - t_1) \text{ x } (L_2 - L_1)}$$

Where,

NAR= Net assimilation rate
W_1 and W_2 is dry weight of whole plant at time t_1 and t_2, respectively
L_1 and L_2 are leaf dry weights at time t_1 and t_2, respectively
t_1 - t_2 are time interval in day

3.6.2 Yield attributes

3.6.2.1 Number of pods plant^{-1}

The number of pods per plant was counted from the five tagged plants in each plot and the average was recorded as the numbers of pods plant^{-1}.

3.6.2.2 Pod length (cm)

The five tagged plants after harvest for each plot were measured and the average was recorded as the length of pods.

3.6.2.3 Number of seeds pod^{-1}

The number of seeds per pod was counted from five (5) tagged plants from each plot and mean was calculated for statistical analysis.

3.6.2.4 Seed index (100 - grain wt.)

A hundred seeds were randomly taken from the finally cleaned produce of each plot for the recording test weight. Then, the weight of 100 seeds of each plot was recorded separately on an electrical balance.

3.6.2.5 Seed yield (kg ha^{-1})

The seed yield per sq. meter area was recorded after winnowing the seed with the help of digital balance. Finally, the seed yield of each plot was converted into seed yield per hectare by multiplying it with the appropriate conversion factor.

3.6.2.6 Stover yield (kg ha^{-1})

The stover yield per sq. meter area was determined by subtracting the seed yield (Economic yield) of each plot from the biological yield (Bundle weight) of the same plot. This was later converted into stover yield per hectare by multiplying with the same conversion factor used in the case of seed yield per hectare.

3.6.2.7 Biological yield (kg ha^{-1})

The whole weight after sun drying, bundle of each net plot produce was measured using a digital hanging balance and converted in kg ha^{-1}.

3.6.2.8 Harvest index

It is the ratio of economic yield to the biological yield. It was determined with the help of following formula and expressed in percentage as follows. It was calculated by using the following formula of Nichiposovich (1967).

$$\text{Harvest index} = \frac{\text{Economic yield (seed yield)}}{\text{Biological yield (seed and stover yields)}} \times 100$$

3.7 Herbicide residue (bioassay studies)

Bioassay is a major tool for quantitative and qualitative determination of herbicide residues. In this method, the property of a chemical is measured in terms of some biological responses. The response is measured through two different types viz., (i) plant part response and (ii) total plant response (Lavy and Santelmann, 1986). The first procedure i.e. plant part response is adopted in this experiment.

In this method, herbicidal persistence in the soils of the experimental plots was monitored at 30, 60, 90 and 120 day intervals during the growing seasons using the method of field bioassay.

Composite soil samples from 0–15 cm depth was collected from each of the experimental plots at a 30-day interval. A composite sample of 800 g was taken in bioassay plates/petri plates.

Bioassay plates were filled with soil collected from each plot and five seeds of each oat, mustard, cucumber, and maize were shown on bioassay plates. These plates were placed in the laboratory and water regularly to prevent desiccation. After 8 days, all the seedlings were uprooted, and the roots were washed gently to remove soil. Then, root and shoot length of these seedling were measured.

3.8 Soil microbiological analysis

Soil samples for microbial analysis were collected from each plot at harvest and taken to the soil laboratory and kept air dry. Further, soil samples were prepared for microbial analysis through the serial dilution agar-plating method as follows: Five test tubes containing 9 ml of sterile distilled water were taken. One test tube containing 10 ml of sterile distilled water was taken and added 1 g of soil to the tube. Thereafter, the soil was mixed thoroughly with the sterile distilled water. Then 1 ml of microbial suspension was added to another test tube containing 9 ml of sterile distilled water and thoroughly mixed. Further, 1 ml of microbial suspension was added to another test tube containing 9 ml of sterile distilled water. The same step was repeated serially up to 106 dilutions. From that dilution, 0.1 ml of soil water suspension was transferred, spread uniformly, and inoculated in nutrient agar plates. The colonies of bacteria were counted using a colony counter and expressed in cfu × 106 g^{-1} soil on a dry weight basis. The same procedure was carried out in actinomycetes and fungi.

3.8.1 Bacteria (× 106 cfu g^{-1} soil)

Nutrient agar medium was used for enumeration of bacteria.

3.8.2 Actinomycetes (× 105 cfu g^{-1} soil)

Nutrient agar medium was used for enumeration of actinomycetes.

3.8.3 Fungi (× 103 cfu g^{-1} soil)

Potato dextrose agar medium was used for enumeration of fungi.

3.9 Chemical analysis of soil samples

3.9.1 Soil analysis

After the harvest of the crop, the soil samples were collected treatment wise from the experimental field to determine the nutrient status of the soil. The samples were analysed for pH, electrical conductivity, organic carbon, available nitrogen, available phosphorus, and available potassium.

3.9.1.1 Soil pH

Soil pH was determined in the soil: water (1:2) ratio by a digital pH meter (Jackson, 1973).

3.9.1.2 Soil electrical conductivity (EC)

Soil EC was determined by southbridge methods (Jackson, 1973).

3.9.1.3 Organic carbon

Organic carbon was determined by rapid titrimetric determination (Walkley and Black, 1934), and the results were expressed in percentages.

3.9.1.4 Available Nitrogen (kg ha^{-1})

The soil's available nitrogen was determined by alkaline potassium permanganate ($KMnO_4$) method proposed by Subbiah and Asija (1956) with the help of 'Kel Plus' nitrogen distillation machine. The data was calculated in terms of kg ha^{-1}.

3.9.1.5 Available Phosphorus (kg ha^{-1})

The available soil phosphorus was determined by Bray's No. 1 method proposed by Bray and Kurtz (1945) using 0.03 N NH_4F + 0.025 N HCL (pH 3.5) as an extracting solution. In the filtered extract, phosphorus was estimated using spectrophotometers by adding ammonium molybdate and stannous chloride. The intensity (% transmittance) of characteristics of blue colour in the solution gives the measure for the concentration of P in the test solution, which was read in the spectrometer at 660 nm wavelength. After getting the % transmittance of the P in the test solution, the concentration of P was read from the standard curve. The results were expressed in kg ha^{-1}. This method is primarily meant for soils with moderate to strong acids with a pH of around 5.5 or less.

3.9.1.6 Available Potassium (kg ha^{-1})

Available Potassium was extracted from 5 g of soil by shaking with 25 ml of neutral ammonium acetate (pH 7.0) solution for 5 minutes. The extract was filtered immediately through a dry filter paper (Whatman No.1) and then potassium concentration in the extract was determined using neutral normal ammonium acetate methods (Hanway and Heidal, 1952). It was expressed in terms of kg ha^{-1}.

3.9.2 Plant analysis

3.9.2.1 N, P and K depletion by Weeds

Weed samples were drawn from each plot at 60 DAS of the crop for determination of N, P, and K content in weed plants. Collected samples were dried and grinded thoroughly and analyzed as per standard procedure of modified Kjeldahl method for N, Vanadomolybdo-phosphoric yellow colour method (Jackson, 1973) for P and flame photometric method for K as suggested by Jackson, (1973).

Nutrient depletion (kg ha^{-1}) =

$$\frac{\text{Nutrient (\%) in weeds x weed dry matter production (kg ha}^{-1}\text{)}}{100}$$

3.9.2.2 N, P and K content and uptake in grain and straw

Randomly selected plant samples were collected treatment wise for chemical estimation. Straw and grains were separated, air-dried and finally oven dried at a temperature of 65 to 70°C and grinded. Seed and straw samples were analyzed for nitrogen by modified Kjeldahl's method (Jackson, 1973), phosphorus by di-acid digestion and yellow colour development method (Jackson, 1973) and potassium by flame photometric method (Jackson, 1973).

The uptake was further calculated by using the formula

Nutrient depletion (kg ha^{-1}) =

$$\frac{\text{Nutrient content (\%) in grain or straw x grain or straw (kg ha}^{-1}\text{)}}{100}$$

3.10 Economic analysis

The economics of various treatments was worked out taking into account the existing market rate of various production factors and produce during the course of investigation. The details with respect to economics analysis have been given in Appendix.

3.10.1 Cost of cultivation (₹ ha^{-1})

Cost of cultivation is an important factor for economic analysis. It can be calculated by considering the prevailing market price of inputs, wages, and actual cost involved in various aspects during the course of investigation.

3.12.2 Net monetary returns (₹ ha^{-1})

The net monetary returns (₹ ha^{-1}) were calculated after deducting all the expenditure (₹ ha^{-1}) from gross return. It was obtained by subtracting cost of cultivation from gross return. This represents the actual income of farmer.

The net monetary returns (₹ ha^{-1}) for different treatments were calculated with the following formula-

Net monetary returns (₹ ha^{-1}) = Gross returns (₹ ha^{-1}) – Cost of cultivation (₹ ha^{-1})

3.10.3 Benefit-cost ratio (B: C)

To estimate the benefits obtained under different treatments for each rupee of expenditure incurred, B: C ratio of each treatment was calculated as below: -

$$\text{B: C ratio} = \frac{\text{Net monetary returns}}{\text{Total cost of cultivation}}$$

3.11 Statistical analysis

The collected data was processed, classified, tabulated systematically and statistically analysed by using two-way analysis of variance (ANOVA). Further, differences between treatments were analysed by using ANOVA at a significance level of 0.05 and the significant of different source of variations was tested by ‘F’ test to find out the significant differences between mean values (Gomez & Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

RESULT AND DISCUSSION

The results of the present experiment entitled "Evaluation of herbicides for weed management in soybean (*Glycine max* L. Merill) and its residual effect on succeeding linseed (*Linum usitatissimum*)" are presented in this chapter. The data about growth attributes, weed observations, herbicide residue (by field bioassay), residual effect on succeeding crops, soil and plant analysis, and economics have been analysed to determine the degree of variation induced by various weed management techniques and were recorded to draw a valid conclusion. They were subjected to statistical analysis and analysis of variance. The mean values of different variables are presented in the table and represented graphically wherever possible throughout this chapter.

4.1 Observation on weed

4.1.1 Weed flora of soybean.

The weed flora of the experiment field is been depicted in Table 4.1 and various weed flora viz. broad-leaved weed, grasses and sedges have been mentioned.

Table 4.1 Weed flora of the experimental field

Scientific name	Common name	Family	Ontogeny
broad leaf weeds			
Mollugo pentaphylla	Carpet weed	Molluginaceae	Annual
Borreria latifolia	Boardleaf buttonweed	Rubiaceae	Annual
Mimosa pudica	Touch me not	Fabaceae	Annual
Ageratum conyzoides	Billy goat weed	Asteraceae	Annual
Amaranthus viridies	Green amarnath	Amaranthaceae	Annual
Portulaca oleracea	Purserly	Portulacaceae	Annual

Alternanthera sessilis	Dwarf copperleaf	Amaranthaceae	Perennial
Cleome rutidosperma	Fringed spider flower	Cleomaceae	Annual
Sedges			
Cyperus rotundus	Purpule nut sedge	Cyperaceae	Perennial
Cyperus iria	Rice flat sedge	Cyperaceae	Annual
Grasses			
Digitaria sanguanalis	Crab grass	Poaceae	Annual
Eleusine indica	Goose grass	Poaceae	Annual
Cynodon dactylon	Doob grass	Poaceae	Perennial

The weed flora in the experimental fields was dominated by three grass species, two sedge species, and eight broadleaved weed species. Among the grasses *Digitaria sanguanalis, Eleusine indica and Cynodon dactylon* were dominant weed. *Cyperus rotundus, Cyperus iria* were sedges weeds. The predominant broad leaves were *Mollugo pentaphylla, Borreria latifolia, Mimosa pudica, Ageratum conyzoides, Amaranthus viridies, Portulaca oleracea, Alternanthera sessilis* and *Cleome rutidosperma* found in the experimental fields. Similar finding has been observed by Walling *et al* (2012), Longchar and Longkumer (2015) and Apon and Nongmaithem (2022).

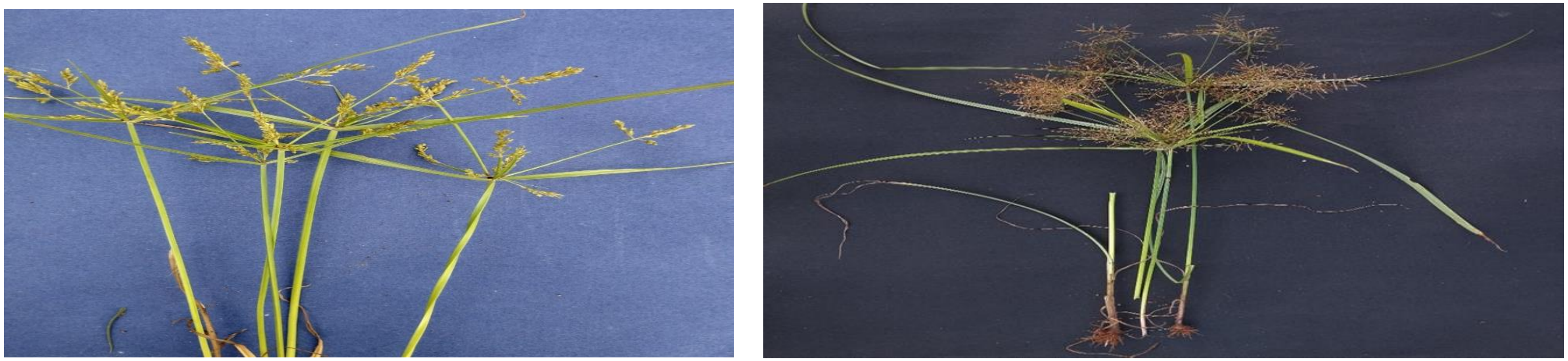
4.1.2 Species wise weed count

4.1.2.1 Effect of weed management treatments on weed density (no. m^{-2}) of *Digitaria sanguinalis.*

Digitaria sanguinalis was one of the dominant weeds on the experimental field and stood first with respect to observed data. The data on weed density of *Digitaria sanguinalis* under different treatments recorded at 20, 40, 60 days after sowing (DAS) and at harvest are presented in Table 4.1.2. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Digitaria sanguinalis* at all growth stages.

Digitaria sanguinalis *Eleusine indica* *Cynadon dactylon*

Plate 1. **Grasses weed observed in the experimental field**



Cyperus iria *Cyperus rotundus*

Plate 2. Sedges weed observed in the experimental field

Ageratum conyzoides

Amaranthus viridis

Borreria latifolia

Cleome rutidosperma

Mollugo pentaphylla

Mimosa pudica

Portulaca oleracea

Alternanthera sessilis

Plate 3. Broadleaf weed observed in the experimental field

Data revealed that at 20 DAS treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (4.83 m^{-2}) for *Digitaria sanguinalis,* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) resulted the lowest weed density (3.94 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (3.76 m^{-2} and 3.29 m^{-2}) among the weed control treatments. Whereas, in all the stages, unweeded control (T_8) recorded the highest weed density of for *Digitaria sanguinalis* among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Madhu *et al*. 2022 and Katoch *et al*., 2023 in chickpea and mungbean at 20 DAS with the treatment of Pendimethalin *fb* interculture. Such results were also observed by Borje *et al*. (2023).

4.1.2.2 Effect of weed management treatments on weed density (no. m^{-2}) of *Eleusine indica*

In field trial, the data on weed density of *Eleusine indica* was another dominant weed. The effect of weed management under different treatments recorded at 20, 40, 60 days after sowing (DAS) and at harvest are presented in Table 4.1.3. The perusal of data revealed that there was significant difference on *Eleusine indica* density due to the effect of treatments and significantly reduces as the advancement of crop, whereas control showed higher density at all stages.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (3.48 m^{-2}) for *Eleusine indica,* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (2.86 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (2.88 m^{-2} and 2.67 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 4.03 m^{-2}, 40 DAS-5.10 m^{-2}, 60 DAS-5.32 m^{-2} and at harvest-5.02 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Walling *et al*. (2012), Madhu *et al*. (2022) and Katoch *et al*. (2023).

Table 4.1.2 Effect of weed management on weed density (no. m^{-2}) of *Digitaria sanguinalis.*

Weed density (no. m^{-2}) of *Digitaria sanguinalis*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	4.90 (23.50)	4.77 (22.22)	4.83 (22.86)	5.45 (29.28)	5.41 (28.81)	5.43 (29.05)	5.59 (30.74)	5.52 (29.96)	5.55 (30.35)	5.01 (24.60)	4.75 (22.10)	4.88 (23.35)
T_2	4.77 (22.22)	4.70 (21.61)	4.73 (21.92)	4.18 (17.00)	4.13 (16.59)	4.15 (16.80)	4.63 (20.95)	4.49 (19.67)	4.56 (20.31)	4.07 (16.08)	3.85 (14.31)	3.96 (15.19)
T_3	6.49 (41.64)	6.20 (38.01)	6.35 (39.82)	5.21 (26.62)	5.13 (25.81)	5.17 (26.21)	5.30 (27.57)	5.21 (26.62)	5.25 (27.10)	4.47 (19.53)	4.45 (19.28)	4.46 (19.41)
T_4	5.59 (30.77)	5.32 (27.82)	5.45 (29.29)	3.96 (15.22)	3.93 (14.92)	3.94 (15.07)	4.31 (18.11)	4.31 (18.06)	4.31 (18.09)	3.87 (14.47)	3.70 (13.16)	3.78 (13.81)
T_5	6.50 (41.74)	6.23 (38.31)	6.36 (40.03)	5.23 (26.86)	5.20 (26.58)	5.22 (26.72)	5.44 (29.07)	5.27 (27.26)	5.35 (28.16)	4.68 (21.39)	4.72 (21.77)	4.70 (21.58)
T_6	5.62 (31.12)	5.54 (30.23)	5.58 (30.68)	4.28 (17.82)	4.20 (17.17)	4.24 (17.50)	4.73 (21.95)	4.69 (21.49)	4.71 (21.72)	4.26 (17.61)	4.21 (17.23)	4.23 (17.42)
T_7	6.49 (41.62)	6.19 (37.79)	6.34 (39.71)	4.69 (21.50)	4.74 (21.94)	4.71 (21.72)	3.87 (14.49)	3.66 (13.02)	3.76 (13.76)	3.32 (10.53)	3.26 (10.12)	3.29 (10.33)
T_8	6.50 (41.98)	6.24 (38.67)	6.37 (40.32)	7.26 (52.27)	7.17 (50.97)	7.22 (51.62)	7.39 (54.11)	7.36 (53.71)	7.38 (53.91)	7.14 (50.51)	7.00 (48.56)	7.07 (49.54)
SEm±	0.14	0.14	0.10	0.11	0.09	0.07	0.10	0.12	0.08	0.06	0.04	0.03
CD (P=0.05)	0.42	0.41	0.28	0.35	0.28	0.21	0.29	0.37	0.23	0.17	0.12	0.10

Figures in parenthesis are original values; Data is subjected to square root transformation ***CD (P=0.05)***

4.1.2.3 Effect of weed management treatments on weed density (no. m^{-2}) of *Cynodon dactylon*.

The data on weed density of *Cynodon dactylon* under different treatments recorded at 20, 40, 60 days after sowing (DAS) and at harvest are presented in Table 4.1.4. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Cynodon dactylon*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.20 m^{-2}) for *Cynodon dactylon* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.14 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.16 m^{-2} and 1.13 m^{-2}) among the weed control treatments. Walling *et al*. (2012) also found similar findings. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 1.49 m^{-2}, 40 DAS-1.64 m^{-2}, 60 DAS-1.70 m^{-2} and at harvest-1.68 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Borana *et al*. (2017)

4.1.2.4 Effect of weed management treatments on weed density (no. m^{-2}) of *Mollugo pentaphylla*.

The data on weed density of *Mollugo pentaphylla* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.5. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Mollugo pentaphylla*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (3.03 m^{-2}) for *Mollugo pentaphylla* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.53 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (2.12

Table 4.1.3 Effect of weed management on weed density (no. m^{-2}) of *Eleusine indica*

Weed density (no. m^{-2}) of *Eleusine indica*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	3.58 (12.35)	3.37 (10.89)	3.48 (11.62)	3.64 (12.77)	3.67 (12.95)	3.65 (12.86)	3.86 (14.37)	3.77 (13.73)	3.81 (14.05)	3.43 (11.24)	3.32 (10.53)	3.37 (10.88)
T_2	3.51 (11.89)	3.34 (10.64)	3.43 (11.27)	2.90 (7.90)	2.86 (7.71)	2.88 (7.80)	3.52 (11.89)	3.32 (10.55)	3.42 (11.22)	3.22 (9.90)	3.02 (8.67)	3.12 (9.29)
T_3	3.96 (15.21)	3.95 (15.12)	3.95 (15.17)	3.43 (11.26)	3.40 (11.09)	3.42 (11.17)	3.61 (12.56)	3.54 (12.00)	3.57 (12.28)	3.32 (10.52)	3.15 (9.42)	3.23 (9.97)
T_4	3.66 (12.89)	3.41 (11.13)	3.53 (12.01)	2.89 (7.84)	2.83 (7.52)	2.86 (7.68)	3.45 (11.44)	3.26 (10.13)	3.36 (10.78)	3.17 (9.61)	2.99 (8.45)	3.08 (9.03)
T_5	4.02 (15.64)	3.99 (15.40)	4.00 (15.52)	3.52 (11.90)	3.63 (12.65)	3.57 (12.28)	3.81 (14.04)	3.67 (13.00)	3.74 (13.52)	3.38 (10.94)	3.25 (10.07)	3.32 (10.51)
T_6	3.67 (13.01)	3.60 (12.45)	3.64 (12.73)	2.90 (7.92)	2.89 (7.88)	2.90 (7.90)	3.54 (12.01)	3.41 (11.13)	3.47 (11.57)	3.29 (10.31)	3.14 (9.34)	3.21 (9.82)
T_7	3.68 (13.12)	3.66 (12.92)	3.67 (13.02)	3.10 (9.12)	3.12 (9.26)	3.11 (9.19)	2.86 (7.71)	2.90 (7.89)	2.88 (7.80)	2.69 (6.73)	2.65 (6.53)	2.67 (6.63)
T_8	4.08 (16.14)	3.99 (15.47)	4.03 (15.80)	5.20 (26.51)	5.01 (24.62)	5.10 (25.56)	5.39 (28.58)	5.24 (26.95)	5.32 (27.77)	5.06 (25.08)	4.97 (24.25)	5.02 (24.67)
SEm±	0.12	0.09	0.07	0.05	0.05	0.04	0.07	0.05	0.04	0.08	0.07	0.05
CD (P=0.05)	0.37	0.26	0.21	0.16	0.17	0.11	0.20	0.16	0.12	0.24	0.21	0.15

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.4 Effect of weed management on weed density (no. m^{-2}) of *Cynodon dactylon*

Weed density (no. m^{-2}) of *Cynodon dactylon*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	1.20 (0.95)	1.19 (0.92)	1.20 (0.94)	1.23 (1.02)	1.22 (0.99)	1.23 (1.01)	1.35 (1.33)	1.33 (1.27)	1.34 (1.30)	1.33 (1.20)	1.29 (1.16)	1.31 (1.18)
T$_2$	1.20 (0.95)	1.19 (0.92)	1.20 (0.93)	1.15 (0.83)	1.15 (0.83)	1.15 (0.83)	1.25 (1.07)	1.27 (1.11)	1.26 (1.09)	1.22 (0.99)	1.21 (0.97)	1.22 (0.98)
T$_3$	1.45 (1.61)	1.43 (1.54)	1.44 (1.58)	1.18 (0.90)	1.18 (0.90)	1.18 (0.90)	1.29 (1.15)	1.28 (1.15)	1.28 (1.15)	1.26 (1.10)	1.24 (1.05)	1.25 (1.07)
T$_4$	1.20 (0.95)	1.19 (0.92)	1.20 (0.94)	1.14 (0.80)	1.14 (0.80)	1.14 (0.80)	1.23 (1.01)	1.24 (1.03)	1.23 (1.02)	1.20 (0.94)	1.17 (0.88)	1.19 (0.91)
T$_5$	1.47 (1.65)	1.45 (1.60)	1.46 (1.62)	1.18 (0.89)	1.18 (0.89)	1.18 (0.89)	1.32 (1.23)	1.30 (1.19)	1.31 (1.21)	1.29 (1.15)	1.26 (1.08)	1.27 (1.12)
T$_6$	1.20 (0.95)	1.20 (0.94)	1.20 (0.94)	1.15 (0.83)	1.15 (0.83)	1.15 (0.83)	1.27 (1.12)	1.26 (1.08)	1.27 (1.10)	1.26 (1.08)	1.24 (1.04)	1.25 (1.06)
T$_7$	1.20 (0.93)	1.20 (0.93)	1.20 (0.93)	1.17 (0.88)	1.17 (0.88)	1.17 (0.88)	1.16 (0.84)	1.15 (0.83)	1.16 (0.84)	1.14 (0.81)	1.12 (0.77)	1.13 (0.79)
T$_8$	1.51 (1.80)	1.46 (1.62)	1.49 (1.71)	1.65 (2.23)	1.62 (2.14)	1.64 (2.18)	1.71 (2.43)	1.69 (2.36)	1.70 (2.40)	1.69 (2.35)	1.67 (2.28)	1.68 (2.32)
SEm±	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.02	0.03
CD (P=0.05)	0.04	0.02	0.02	0.04	0.03	0.02	0.03	0.03	0.02	0.17	0.06	0.09

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.5 Effect of weed management on weed density (no. m^{-2}) of *Mollugo pentaphyll*

Weed density (no. m^{-2}) of *Mollugo pentaphylla*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	3.04 (8.77)	3.02 (8.64)	3.03 (8.71)	3.53 (11.96)	3.52 (11.91)	3.53 (11.93)	3.60 (12.49)	3.55 (12.25)	3.57 (12.37)	2.93 (8.08)	2.87 (7.78)	2.90 (7.93)
T_2	3.00 (8.49)	2.93 (8.14)	2.97 (8.31)	1.61 (2.10)	1.59 (2.04)	1.60 (2.07)	2.88 (7.87)	2.87 (7.77)	2.88 (7.82)	2.17 (4.20)	2.13 (4.03)	2.15 (4.12)
T_3	4.11 (16.45)	4.11 (16.38)	4.11 (16.41)	2.46 (5.57)	2.43 (5.44)	2.45 (5.50)	2.49 (5.69)	2.45 (5.49)	2.47 (5.59)	1.37 (1.37)	1.33 (1.28)	1.35 (1.32)
T_4	3.34 (10.64)	3.32 (10.55)	3.33 (10.59)	1.54 (1.88)	1.52 (1.82)	1.53 (1.85)	2.18 (4.26)	2.16 (4.17)	2.17 (4.22)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_5	4.09 (16.49)	4.11 (16.42)	4.10 (16.45)	2.56 (6.11)	2.53 (5.93)	2.55 (6.02)	2.81 (7.40)	2.80 (7.34)	2.80 (7.37)	2.13 (4.05)	1.97 (3.38)	2.05 (3.72)
T_6	3.36 (10.77)	3.32 (10.53)	3.34 (10.65)	1.61 (2.16)	1.59 (2.07)	1.60 (2.12)	2.27 (4.64)	2.20 (4.36)	2.24 (4.50)	1.20 (1.06)	1.19 (1.03)	1.20 (1.05)
T_7	4.07 (16.37)	4.09 (16.26)	4.08 (16.31)	2.67 (6.68)	2.65 (6.52)	2.66 (6.60)	2.13 (4.03)	2.12 (4.00)	2.12 (4.01)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_8	4.14 (16.66)	4.14 (16.62)	4.14 (16.64)	4.33 (18.32)	4.33 (18.27)	4.33 (18.29)	4.43 (19.16)	4.41 (18.98)	4.42 (19.07)	3.85 (14.33)	3.83 (14.20)	3.84 (14.27)
SEm±	*0.22*	*0.08*	*0.12*	*0.13*	*0.08*	*0.08*	*0.09*	*0.11*	0.07	*0.10*	*0.12*	*0.08*
CD (P=0.05)	*0.65*	*0.25*	*0.33*	*0.39*	*0.25*	*0.22*	*0.26*	*0.32*	0.20	*0.31*	*0.36*	*0.23*

Figures in parenthesis are original values; Data is subjected to square root transformation

m^{-2} and 0.71 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 4.14 m^{-2}, 40 DAS-4.33 m^{-2}, 60 DAS-4.42 m^{-2} and at harvest-3.84 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Panda *et al*. (2015) and Patidar *et al*. (2019 b).

4.1.2.5 Effect of weed management treatments on weed density (no. m^{-2}) of *Borreria latifolia*.

The data on weed density of *Borreria latifolia* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.6. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Borreria latifolia*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (3.37 m^{-2}) for *Borreria latifolia* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (2.61 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (2.44 m^{-2} and 2.10 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 4.19 m^{-2}, 40 DAS- 4.42 m^{-2}, 60 DAS- 4.83 m^{-2} and at harvest- 4.66 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Apon and Nongmaithem (2022).

4.1.2.6 Effect of weed management treatments on weed density (no. m^{-2}) of *Mimosa pudica*.

The data on weed density of *Mimosa pudica* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.7. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Mimosa pudica*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (2.05 m^{-2}) for *Mimosa pudica* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.76 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.93 m^{-2} and 1.50 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 3.07 m^{-2}, 40 DAS-3.34 m^{-2}, 60 DAS-3.56 m^{-2} and at harvest-3.13 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar trend was observed by Meena *et al*. (2011).

4.1.2.7 Effect of weed management treatments on weed density (no. m^{-2}) of *Ageratum conyzoides*.

The data on weed density of *Ageratum conyzoides* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.8. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Ageratum conyzoides*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.85 m^{-2}) for *Ageratum conyzoides* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.69 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.65 m^{-2} and 0.71 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 3.41 m^{-2}, 40 DAS- 3.70 m^{-2}, 60 DAS- 3.85 m^{-2} and at harvest- 3.57 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Emmiganur and Hosmath (2020).

4.1.2.8 Effect of weed management treatments on weed density (no. m^{-2}) of *Amaranthus viridis*.

The data on weed density of *Amaranthus viridis* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.9. The perusal of

Table 4.1.6 Effect of weed management on weed density (no. m^{2}) of *Borreria latifolia*

Weed density (no. m^{-2}) of *Borreria latifolia*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	3.52 (11.97)	3.23 (9.92)	3.37 (10.95)	3.60 (12.49)	3.56 (12.16)	3.58 (12.33)	4.01 (15.63)	3.98 (15.41)	3.99 (15.52)	3.82 (14.11)	3.78 (13.88)	3.80 (14.00)
T_2	3.40 (11.38)	3.22 (9.88)	3.31 (10.63)	2.69 (6.74)	2.68 (6.69)	2.69 (6.71)	3.50 (11.79)	3.40 (11.06)	3.45 (11.42)	3.28 (10.27)	3.17 (9.53)	3.22 (9.90)
T_3	4.22 (17.34)	4.13 (16.56)	4.17 (16.95)	3.23 (9.96)	3.18 (9.64)	3.20 (9.80)	3.33 (10.62)	3.29 (10.39)	3.31 (10.51)	3.10 (9.10)	3.05 (8.86)	3.07 (8.98)
T_4	3.73 (13.47)	3.47 (11.55)	3.60 (12.51)	2.63 (6.41)	2.59 (6.21)	2.61 (6.31)	2.84 (7.58)	2.64 (6.59)	2.74 (7.09)	2.55 (6.06)	2.32 (5.06)	2.44 (5.56)
T_5	4.23 (17.47)	4.13 (16.54)	4.18 (17.00)	3.30 (10.38)	3.27 (10.26)	3.29 (10.32)	3.47 (11.57)	3.46 (11.45)	3.46 (11.51)	3.25 (10.05)	3.23 (9.92)	3.24 (9.99)
T_6	3.94 (15.13)	3.55 (12.09)	3.75 (13.61)	2.76 (7.16)	2.74 (7.02)	2.75 (7.09)	2.90 (7.89)	2.81 (7.45)	2.85 (7.67)	2.62 (6.37)	2.52 (5.92)	2.57 (6.15)
T_7	4.21 (17.29)	4.09 (16.23)	4.15 (16.76)	3.37 (10.84)	3.33 (10.62)	3.35 (10.73)	2.47 (5.67)	2.40 (5.29)	2.44 (5.48)	2.14 (4.15)	2.06 (3.76)	2.10 (3.95)
T_8	4.24 (17.49)	4.14 (16.62)	4.19 (17.06)	4.43 (19.12)	4.42 (19.05)	4.42 (19.08)	4.84 (23.03)	4.81 (22.67)	4.83 (22.85)	4.68 (21.51)	4.65 (21.14)	4.66 (21.32)
SEm±	*0.21*	*0.09*	*0.12*	*0.08*	*0.09*	*0.06*	*0.12*	*0.15*	*0.10*	*0.13*	*0.17*	*0.11*
CD (P=0.05)	*0.65*	*0.29*	*0.34*	*0.25*	*0.28*	*0.18*	*0.35*	*0.46*	*0.28*	*0.38*	*0.51*	*0.31*

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.7 Effect of weed management on weed density (no. m^{-2}) of *Mimosa pudica*

Weed density (no. m^{-2}) of *Mimosa pudica*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	2.09 (3.88)	2.04 (3.68)	2.07 (3.78)	2.55 (6.05)	2.55 (6.01)	2.55 (6.03)	3.09 (9.06)	3.07 (8.93)	3.08 (9.00)	2.63 (6.44)	2.55 (6.04)	2.59 (6.24)
T_2	2.07 (3.82)	2.03 (3.63)	2.05 (3.73)	1.79 (2.71)	1.76 (2.59)	1.77 (2.65)	2.33 (4.92)	2.31 (4.85)	2.32 (4.88)	1.77 (2.64)	1.74 (2.53)	1.76 (2.59)
T_3	3.08 (9.02)	3.05 (8.82)	3.06 (8.92)	2.31 (4.86)	2.30 (4.78)	2.31 (4.82)	2.87 (7.76)	2.84 (7.57)	2.86 (7.67)	2.15 (4.12)	2.14 (4.07)	2.14 (4.10)
T_4	2.67 (6.65)	2.63 (6.46)	2.65 (6.55)	1.77 (2.62)	1.75 (2.57)	1.76 (2.59)	2.25 (4.57)	2.20 (4.32)	2.22 (4.45)	1.65 (2.22)	1.63 (2.14)	1.64 (2.18)
T_5	3.09 (9.04)	3.06 (8.85)	3.07 (8.94)	2.32 (4.89)	2.28 (4.73)	2.30 (4.81)	2.85 (7.61)	2.81 (7.38)	2.83 (7.50)	2.12 (4.04)	2.10 (3.92)	2.11 (3.98)
T_6	2.73 (6.96)	2.69 (6.74)	2.71 (6.85)	1.80 (2.73)	1.79 (2.69)	1.79 (2.71)	2.30 (4.81)	2.27 (4.64)	2.28 (4.72)	1.74 (2.52)	1.70 (2.38)	1.72 (2.45)
T_7	3.08 (9.00)	3.04 (8.78)	3.06 (8.89)	2.41 (5.33)	2.39 (5.21)	2.40 (5.27)	1.93 (3.24)	1.92 (3.20)	1.93 (3.22)	1.55 (1.90)	1.46 (1.63)	1.50 (1.76)
T_8	3.08 (9.04)	3.06 (8.87)	3.07 (8.95)	3.34 (10.67)	3.33 (10.61)	3.34 (10.64)	3.57 (12.31)	3.55 (12.13)	3.56 (12.22)	3.14 (9.39)	3.12 (9.26)	3.13 (9.32)
SEm±	*0.11*	*0.07*	*0.06*	*0.07*	*0.05*	*0.05*	*0.08*	*0.03*	*0.04*	*0.07*	*0.05*	*0.04*
CD (P=0.05)	*0.33*	*0.21*	*0.18*	*0.22*	*0.16*	*0.13*	*0.23*	*0.11*	*0.12*	*0.22*	*0.14*	*0.13*

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.8 Effect of weed management on weed density (no. m^{-2}) of *Ageratum conyzoides*

Weed density (no. m^{-2}) of *Ageratum conyzoides*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	1.89 (3.09)	1.83 (2.84)	1.86 (2.97)	2.46 (5.57)	2.45 (5.53)	2.46 (5.55)	3.18 (9.65)	3.16 (9.47)	3.17 (9.56)	2.67 (6.64)	2.60 (6.33)	2.64 (6.49)
T$_2$	1.87 (3.01)	1.82 (2.81)	1.85 (2.91)	1.78 (2.67)	1.77 (2.64)	1.78 (2.65)	2.30 (4.80)	2.29 (4.74)	2.30 (4.77)	1.58 (2.01)	1.49 (1.71)	1.54 (1.86)
T$_3$	3.41 (11.18)	3.41 (11.15)	3.41 (11.16)	2.22 (4.45)	2.22 (4.41)	2.22 (4.43)	2.66 (6.55)	2.65 (6.50)	2.65 (6.53)	2.03 (3.62)	1.97 (3.37)	2.00 (3.50)
T$_4$	2.49 (5.72)	2.49 (5.69)	2.49 (5.71)	1.70 (2.39)	1.68 (2.34)	1.69 (2.36)	2.22 (4.44)	2.21 (4.40)	2.22 (4.42)	1.37 (1.38)	1.30 (1.20)	1.33 (1.29)
T$_5$	3.41 (11.22)	3.42 (11.17)	3.41 (11.20)	2.25 (4.54)	2.23 (4.49)	2.24 (4.52)	2.59 (6.22)	2.58 (6.17)	2.59 (6.20)	1.95 (3.31)	1.90 (3.12)	1.93 (3.22)
T$_6$	2.51 (5.84)	2.50 (5.77)	2.51 (5.80)	1.81 (2.78)	1.80 (2.75)	1.80 (2.77)	2.28 (4.71)	2.27 (4.66)	2.28 (4.69)	1.41 (1.49)	1.34 (1.29)	1.37 (1.39)
T$_7$	3.41 (11.15)	3.40 (11.12)	3.41 (11.14)	2.25 (4.58)	2.24 (4.54)	2.25 (4.56)	1.65 (2.31)	1.66 (2.26)	1.65 (2.28)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T$_8$	3.41 (11.25)	3.42 (11.20)	3.41 (11.22)	3.71 (13.26)	3.70 (13.17)	3.70 (13.22)	3.86 (14.37)	3.84 (14.25)	3.85 (14.31)	3.58 (12.34)	3.56 (12.17)	3.57 (12.26)
SEm±	*0.14*	*0.06*	*0.08*	*0.07*	*0.03*	*0.04*	*0.08*	*0.04*	*0.05*	*0.03*	*0.08*	*0.04*
CD (P=0.05)	*0.43*	*0.19*	*0.23*	*0.21*	*0.10*	*0.11*	*0.25*	*0.11*	*0.13*	*0.09*	*0.23*	*0.12*

Figures in parenthesis are original values; Data is subjected to square root transformation

data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Amaranthus viridis*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.45 m^{-2}) for *Amaranthus viridis* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.32 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.52 m^{-2} and 1.53 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 2.42 m^{-2}, 40 DAS- 2.72 m^{-2}, 60 DAS- 3.20 m^{-2} and at harvest- 3.16 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was corroborated by Dhaker *et al*. (2009) and Lal *et al*. (2018).

4.1.2.9 Effect of weed management treatments on weed density (no. m^{-2}) of *Portulaca olerecea*.

The data on weed density of *Portulaca olerecea* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.10. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Portulaca olerecea*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.31 m^{-2}) for *Portulaca olerecea* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.27 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.26 m^{-2} and 1.32 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 1.90 m^{-2}, 40 DAS- 2.00 m^{-2}, 60 DAS- 2.16 m^{-2} and at harvest- 2.06 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Ram *et al*. (2013).

4.1.2.10 Effect of weed management treatments on weed density (no. m^{-2}) of *Alternanthera sessilis*.

The data on weed density of *Alternanthera sessilis* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.11. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Alternanthera sessilis*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.84 m^{-2}) for *Alternanthera sessilis* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.78 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.81 m^{-2} and 1.73 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 2.12 m^{-2}, 40 DAS- 2.29 m^{-2}, 60 DAS- 2.28 m^{-2} and at harvest- 2.14 m^{-2}) among the treatments due to more weeds as compared to other treatment.

4.1.2.11 Effect of weed management treatments on weed density (no. m^{-2}) of *Cleome rutidosperma*.

The data on weed density of *Cleome rutidosperma* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.12. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Cleome rutidosperma*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.22 m^{-2}) for *Cleome rutidosperma* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.23 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.25 m^{-2} and 1.25 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 1.40 m^{-2}, 40 DAS- 1.66 m^{-2}, 60

Table 4.1.9 Effect of weed management on weed density (no. m^{-2}) of *Amaranthus viridis*

	Weed density (no. m^{-2}) of *Amaranthus viridis*											
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	1.46 (1.63)	1.44 (1.57)	1.45 (1.60)	2.13 (4.05)	2.11 (3.97)	2.12 (4.01)	2.49 (5.71)	2.47 (5.62)	2.48 (5.66)	2.47 (5.59)	2.45 (5.50)	2.46 (5.54)
T_2	1.45 (1.61)	1.45 (1.59)	1.45 (1.60)	1.35 (1.33)	1.34 (1.30)	1.35 (1.32)	1.81 (2.79)	1.76 (2.60)	1.79 (2.70)	1.81 (2.77)	1.76 (2.59)	1.78 (2.68)
T_3	2.37 (5.24)	2.39 (5.21)	2.38 (5.23)	1.88 (3.03)	1.84 (2.87)	1.86 (2.95)	2.20 (4.33)	2.17 (4.24)	2.19 (4.29)	2.18 (4.26)	2.16 (4.17)	2.17 (4.21)
T_4	2.17 (4.23)	2.14 (4.09)	2.16 (4.16)	1.33 (1.26)	1.31 (1.23)	1.32 (1.24)	1.64 (2.20)	1.62 (2.11)	1.63 (2.16)	1.64 (2.20)	1.62 (2.12)	1.63 (2.16)
T_5	2.40 (5.33)	2.40 (5.26)	2.40 (5.30)	1.98 (3.44)	1.89 (3.07)	1.94 (3.25)	2.18 (4.24)	2.16 (4.17)	2.17 (4.21)	2.16 (4.17)	2.15 (4.11)	2.15 (4.14)
T_6	2.12 (4.00)	2.09 (3.87)	2.10 (3.94)	1.55 (1.91)	1.53 (1.83)	1.54 (1.87)	1.77 (2.65)	1.75 (2.56)	1.76 (2.61)	1.77 (2.63)	1.75 (2.55)	1.76 (2.59)
T_7	2.39 (5.21)	2.38 (5.16)	2.38 (5.19)	2.03 (3.63)	2.02 (3.57)	2.03 (3.60)	1.54 (1.89)	1.51 (1.77)	1.52 (1.83)	1.54 (1.90)	1.51 (1.79)	1.53 (1.85)
T_8	2.43 (5.39)	2.41 (5.30)	2.42 (5.34)	2.74 (6.99)	2.70 (6.80)	2.72 (6.89)	3.21 (9.83)	3.20 (9.72)	3.20 (9.77)	3.17 (9.56)	3.15 (9.45)	3.16 (9.51)
SEm±	*0.13*	*0.04*	*0.07*	*0.06*	*0.05*	*0.04*	*0.05*	*0.05*	*0.03*	*0.04*	*0.04*	*0.03*
CD (P=0.05)	*0.40*	*0.13*	*0.20*	*0.17*	*0.15*	*0.11*	*0.14*	*0.15*	*0.10*	*0.13*	*0.13*	*0.09*

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.10 Effect of weed management on weed density (no. m^{-2}) of *Portulaca oleracea*

Weed density (no. m^{-2}) of *Portulaca olerecea*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	1.32 (1.27)	1.32 (1.24)	1.32 (1.25)	1.38 (1.40)	1.36 (1.36)	1.37 (1.38)	1.90 (3.12)	1.89 (3.09)	1.90 (3.10)	1.84 (2.89)	1.84 (2.87)	1.84 (2.88)
T$_2$	1.32 (1.25)	1.30 (1.20)	1.31 (1.22)	1.28 (1.15)	1.28 (1.13)	1.28 (1.14)	1.44 (1.58)	1.38 (1.43)	1.41 (1.51)	1.46 (1.65)	1.42 (1.53)	1.44 (1.59)
T$_3$	1.90 (3.11)	1.88 (3.04)	1.89 (3.08)	1.64 (2.19)	1.63 (2.16)	1.64 (2.18)	1.76 (2.59)	1.73 (2.50)	1.74 (2.55)	1.72 (2.47)	1.70 (2.40)	1.71 (2.43)
T$_4$	1.55 (1.95)	1.48 (1.68)	1.52 (1.82)	1.27 (1.12)	1.26 (1.09)	1.27 (1.11)	1.36 (1.38)	1.33 (1.27)	1.35 (1.32)	1.40 (1.48)	1.37 (1.39)	1.39 (1.44)
T$_5$	1.91 (3.13)	1.90 (3.10)	1.90 (3.12)	1.65 (2.21)	1.64 (2.19)	1.64 (2.20)	1.73 (2.51)	1.69 (2.38)	1.71 (2.44)	1.70 (2.40)	1.67 (2.30)	1.69 (2.35)
T$_6$	1.60 (2.12)	1.56 (2.04)	1.58 (2.08)	1.34 (1.29)	1.32 (1.25)	1.33 (1.27)	1.41 (1.51)	1.40 (1.46)	1.40 (1.48)	1.44 (1.58)	1.43 (1.55)	1.44 (1.57)
T$_7$	1.89 (3.08)	1.88 (3.03)	1.88 (3.06)	1.69 (2.37)	1.65 (2.24)	1.67 (2.31)	1.28 (1.14)	1.25 (1.06)	1.26 (1.10)	1.34 (1.28)	1.31 (1.22)	1.32 (1.25)
T$_8$	1.90 (3.13)	1.89 (3.09)	1.90 (3.11)	2.01 (3.55)	1.98 (3.43)	2.00 (3.49)	2.17 (4.20)	2.15 (4.16)	2.16 (4.18)	2.07 (3.77)	2.05 (3.74)	2.06 (3.76)
SEm±	*0.09*	*0.08*	*0.06*	*0.05*	*0.03*	*0.03*	*0.06*	*0.08*	*0.05*	*0.05*	*0.07*	*0.04*
CD (P=0.05)	*0.28*	*0.24*	*0.17*	*0.15*	*0.09*	*0.08*	*0.17*	*0.25*	*0.14*	*0.14*	*0.20*	*0.12*

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.11 Effect of weed management on weed density (no. m^{-2}) of *Alternanthera sessilis*

Weed density (no. m^{-2}) of *Alternanthera sessilis*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	1.86 (2.97)	1.83 (2.85)	1.85 (2.91)	1.98 (3.43)	1.96 (3.33)	1.97 (3.38)	2.14 (4.07)	2.11 (3.94)	2.12 (4.01)	2.00 (3.51)	1.96 (3.34)	1.98 (3.43)
T_2	1.86 (2.95)	1.83 (2.84)	1.84 (2.90)	1.79 (2.72)	1.77 (2.62)	1.78 (2.67)	1.92 (3.19)	1.90 (3.09)	1.91 (3.14)	1.79 (2.70)	1.76 (2.61)	1.78 (2.66)
T_3	2.13 (4.06)	2.10 (3.92)	2.12 (3.99)	1.92 (3.18)	1.89 (3.08)	1.90 (3.13)	2.07 (3.80)	2.04 (3.66)	2.06 (3.73)	1.88 (3.02)	1.85 (2.93)	1.86 (2.97)
T_4	2.01 (3.56)	1.98 (3.43)	2.00 (3.49)	1.79 (2.70)	1.77 (2.62)	1.78 (2.66)	1.90 (3.11)	1.87 (2.98)	1.88 (3.05)	1.76 (2.61)	1.74 (2.53)	1.75 (2.57)
T_5	2.14 (4.07)	2.10 (3.93)	2.12 (4.00)	1.92 (3.18)	1.89 (3.07)	1.90 (3.12)	2.06 (3.76)	2.03 (3.62)	2.05 (3.69)	1.87 (3.00)	1.84 (2.90)	1.86 (2.95)
T_6	2.03 (3.62)	2.00 (3.49)	2.01 (3.56)	1.79 (2.72)	1.77 (2.64)	1.78 (2.68)	1.91 (3.16)	1.88 (3.05)	1.90 (3.11)	1.78 (2.68)	1.75 (2.58)	1.77 (2.63)
T_7	2.13 (4.06)	2.10 (3.91)	2.12 (3.99)	1.94 (3.27)	1.92 (3.17)	1.93 (3.22)	1.82 (2.83)	1.80 (2.75)	1.81 (2.79)	1.74 (2.54)	1.71 (2.42)	1.73 (2.48)
T_8	2.14 (4.07)	2.10 (3.93)	2.12 (4.00)	2.22 (4.42)	2.19 (4.29)	2.20 (4.35)	2.29 (4.77)	2.26 (4.61)	2.28 (4.69)	2.15 (4.14)	2.12 (4.01)	2.14 (4.08)
SEm±	*0.03*	*0.02*	*0.02*	*0.02*	*0.01*	*0.01*	*0.02*	*0.01*	*0.01*	*0.02*	*0.01*	*0.01*
CD (P=0.05)	*0.09*	*0.06*	*0.05*	*0.06*	*0.04*	*0.03*	*0.07*	*0.03*	*0.04*	*0.06*	*0.04*	*0.03*

Figures in parenthesis are original values; Data is subjected to square root transformation

DAS- 1.48 m^{-2} and at harvest- 1.47 m^{-2}) among the treatments due to more weeds as compared to other treatment.

4.1.2.12 Effect of weed management treatments on weed density (no. m^{-2}) of *Cyperus rotundus*.

The data on weed density of *Cyperus rotundus* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.13. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Cyperus rotundus*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.27 m^{-2}) for *Cyperus rotundus* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (0.96 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (0.71 m^{-2} and 0.71 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 1.89 m^{-2}, 40 DAS- 2.19 m^{-2}, 60 DAS- 2.41 m^{-2} and at harvest- 2.36 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Virk *et al.* (2018).

4.1.2.13 Effect of weed management treatments on weed density (no. m^{-2}) of *Cyperus iria*.

The data on weed density of *Cyperus iria* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.14. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of *Cyperus iria*.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.35 m^{-2}) for *Cyperus iria* whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.52 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.48 m^{-2} and

Table 4.1.12 Effect of weed management on weed density (no. m^{-2}) of *Cleome rutidosperma*

Weed density (no. m^{-2}) of *Cleome rutidosperma*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	1.23 (1.02)	1.21 (0.96)	1.22 (0.99)	1.24 (1.26)	1.25 (1.19)	1.24 (1.22)	1.34 (1.29)	1.31 (1.21)	1.32 (1.25)	1.33 (1.27)	1.30 (1.20)	1.32 (1.24)
T$_2$	1.23 (1.02)	1.21 (0.95)	1.22 (0.99)	1.23 (1.14)	1.24 (1.07)	1.23 (1.10)	1.32 (1.25)	1.29 (1.18)	1.31 (1.21)	1.32 (1.24)	1.29 (1.16)	1.30 (1.20)
T$_3$	1.41 (1.50)	1.39 (1.43)	1.40 (1.46)	1.24 (1.21)	1.23 (1.14)	1.24 (1.17)	1.31 (1.21)	1.28 (1.14)	1.30 (1.18)	1.31 (1.21)	1.28 (1.13)	1.29 (1.17)
T$_4$	1.33 (1.27)	1.30 (1.20)	1.32 (1.23)	1.23 (1.13)	1.24 (1.06)	1.23 (1.09)	1.28 (1.14)	1.25 (1.07)	1.27 (1.11)	1.27 (1.12)	1.25 (1.05)	1.26 (1.09)
T$_5$	1.42 (1.50)	1.39 (1.43)	1.40 (1.47)	1.24 (1.22)	1.24 (1.15)	1.24 (1.19)	1.32 (1.24)	1.29 (1.16)	1.30 (1.20)	1.31 (1.23)	1.29 (1.16)	1.30 (1.19)
T$_6$	1.34 (1.28)	1.31 (1.21)	1.32 (1.25)	1.25 (1.15)	1.24 (1.09)	1.24 (1.12)	1.29 (1.17)	1.26 (1.09)	1.28 (1.13)	1.29 (1.16)	1.26 (1.09)	1.27 (1.12)
T$_7$	1.41 (1.50)	1.39 (1.42)	1.40 (1.46)	1.23 (1.23)	1.23 (1.16)	1.23 (1.19)	1.26 (1.10)	1.24 (1.03)	1.25 (1.06)	1.26 (1.09)	1.23 (1.02)	1.25 (1.06)
T$_8$	1.42 (1.50)	1.39 (1.43)	1.40 (1.47)	1.65 (1.65)	1.66 (1.57)	1.66 (1.61)	1.49 (1.72)	1.46 (1.63)	1.48 (1.68)	1.49 (1.71)	1.46 (1.62)	1.47 (1.67)
SEm±	*0.01*	*0.01*	*0.01*	*0.03*	*0.02*	*0.02*	*0.01*	*0.02*	*0.01*	*0.01*	*0.01*	*0.01*
CD (P=0.05)	*0.03*	*0.03*	*0.02*	*0.08*	*0.07*	*0.05*	*0.03*	*0.06*	*0.03*	*0.03*	*0.03*	*0.02*

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.13 Effect of weed management on weed density (no. m^{-2}) of *Cyperus rotundus*

Weed density (no. m^{-2}) of *Cyperus rotundus*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	1.32 (1.23)	1.26 (1.08)	1.29 (1.16)	1.76 (2.60)	1.71 (2.43)	1.73 (2.51)	1.83 (2.85)	1.79 (2.72)	1.81 (2.78)	1.65 (2.24)	1.64 (2.20)	1.65 (2.22)
T_2	1.30 (1.19)	1.24 (1.04)	1.27 (1.11)	0.97 (0.48)	0.98 (0.49)	0.98 (0.49)	1.42 (1.52)	1.40 (1.46)	1.41 (1.49)	1.41 (1.49)	1.38 (1.42)	1.40 (1.46)
T_3	1.93 (3.23)	1.83 (2.84)	1.88 (3.03)	1.16 (0.85)	1.16 (0.84)	1.16 (0.85)	1.23 (1.01)	1.22 (1.00)	1.23 (1.01)	1.20 (0.95)	1.17 (0.88)	1.19 (0.91)
T_4	1.69 (2.36)	1.61 (2.11)	1.65 (2.23)	0.96 (0.44)	0.96 (0.46)	0.96 (0.45)	1.12 (0.76)	1.10 (0.71)	1.11 (0.73)	1.09 (0.69)	1.07 (0.66)	1.08 (0.68)
T_5	1.93 (3.24)	1.84 (2.89)	1.89 (3.06)	1.17 (0.86)	1.18 (0.88)	1.17 (0.87)	1.39 (1.43)	1.38 (1.40)	1.38 (1.42)	1.36 (1.35)	1.35 (1.31)	1.35 (1.33)
T_6	1.69 (2.37)	1.62 (2.14)	1.66 (2.25)	1.14 (0.81)	1.14 (0.81)	1.14 (0.81)	1.15 (0.82)	1.14 (0.80)	1.14 (0.81)	1.12 (0.77)	1.11 (0.73)	1.12 (0.75)
T_7	1.85 (2.96)	1.81 (2.80)	1.83 (2.88)	1.36 (1.36)	1.36 (1.35)	1.36 (1.36)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_8	1.94 (3.26)	1.84 (2.90)	1.89 (3.08)	2.20 (4.37)	2.17 (4.22)	2.19 (4.29)	2.43 (5.39)	2.40 (5.27)	2.41 (5.33)	2.37 (5.11)	2.36 (5.06)	2.36 (5.08)
SEm±	*0.06*	*0.06*	*0.04*	*0.08*	*0.07*	*0.05*	*0.02*	*0.04*	*0.02*	*0.04*	*0.03*	*0.02*
CD (P=0.05)	*0.18*	*0.18*	*0.12*	*0.23*	*0.22*	*0.15*	*0.06*	*0.13*	*0.07*	*0.11*	*0.10*	*0.07*

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.14 Effect of weed management on weed density (no. m^{-2}) of *Cyperus iria*

Weed density (no. m^{-2}) of *Cyperus iria*												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	1.36 (1.34)	1.35 (1.32)	1.35 (1.33)	1.72 (2.44)	1.71 (2.42)	1.71 (2.43)	1.75 (2.57)	1.74 (2.54)	1.75 (2.56)	1.73 (2.52)	1.73 (2.50)	1.73 (2.51)
T_2	1.35 (1.33)	1.34 (1.30)	1.35 (1.32)	1.54 (1.88)	1.53 (1.84)	1.54 (1.86)	1.70 (2.39)	1.69 (2.36)	1.69 (2.38)	1.68 (2.34)	1.66 (2.27)	1.67 (2.31)
T_3	2.02 (3.58)	2.01 (3.56)	2.02 (3.57)	1.65 (2.21)	1.63 (2.18)	1.64 (2.20)	1.65 (2.24)	1.65 (2.21)	1.65 (2.23)	1.65 (2.21)	1.63 (2.15)	1.64 (2.18)
T_4	1.73 (2.50)	1.72 (2.48)	1.73 (2.49)	1.53 (1.83)	1.51 (1.79)	1.52 (1.81)	1.55 (1.89)	1.53 (1.85)	1.54 (1.87)	1.52 (1.81)	1.50 (1.76)	1.51 (1.79)
T_5	2.02 (3.59)	2.02 (3.57)	2.02 (3.58)	1.66 (2.27)	1.66 (2.25)	1.66 (2.26)	1.68 (2.33)	1.67 (2.28)	1.68 (2.31)	1.67 (2.30)	1.66 (2.27)	1.67 (2.29)
T_6	1.75 (2.56)	1.74 (2.54)	1.75 (2.55)	1.56 (1.95)	1.56 (1.93)	1.56 (1.94)	1.59 (2.04)	1.55 (1.93)	1.57 (1.99)	1.57 (1.98)	1.57 (1.95)	1.57 (1.97)
T_7	2.01 (3.57)	2.01 (3.54)	2.01 (3.56)	1.68 (2.31)	1.67 (2.29)	1.67 (2.30)	1.48 (1.69)	1.47 (1.66)	1.48 (1.68)	1.47 (1.67)	1.45 (1.61)	1.46 (1.64)
T_8	2.02 (3.59)	2.02 (3.58)	2.02 (3.59)	2.18 (4.27)	2.18 (4.25)	2.18 (4.26)	2.26 (4.59)	2.25 (4.57)	2.25 (4.58)	2.25 (4.56)	2.24 (4.51)	2.24 (4.54)
SEm±	*0.04*	*0.03*	*0.03*	*0.03*	*0.05*	*0.03*	*0.03*	*0.07*	*0.04*	*0.04*	*0.03*	*0.03*
CD (P=0.05)	*0.12*	*0.10*	*0.07*	*0.08*	*0.15*	*0.08*	*0.10*	*0.21*	*0.11*	*0.12*	*0.09*	*0.07*

Figures in parenthesis are original values; Data is subjected to square root transformation

1.46 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 2.02 m^{-2}, 40 DAS- 2.18 m^{-2}, 60 DAS- 2.25 m^{-2} and at harvest- 2.24 m^{-2}) among the treatments due to more weeds as compared to other treatment.

4.1.3 Weed density

4.1.3.1 Effect of weed management treatments on weed density (no. m^{-2}) of grasses.

The data on weed density of *grasses* under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.15. The perusal of the data revealed that there was a significant difference in weed density among the treatments and a significant reduction in the density of grasses.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted in the lowest weed density (5.88 m^{-2}) for grasses, whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted in the lowest weed density (4.90 m^{-2}). At 60 DAS and harvest, T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted in the lowest weed density (4.78 m^{-2} and 4.27 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted in the highest weed density (20 DAS- 7.62 m^{-2}, 40 DAS- 8.94 m^{-2}, 60 DAS- 9.20 m^{-2} and at harvest- 8.78 m^{-2}) among the treatments due to more weeds as compared to other treatments. It may be a fact that herbicides combined with hand weeding or interculture had a profound effect on weeds and drastically decreased their population. Furthermore, the number of weeds was also greatly reduced by combining weed management techniques, including hand weeding and the application of herbicides. The least quantity of weed biomass was produced by hand weeding of all the herbicidal treatments. It turned out that this treatment was significantly more effective. This is an analogy with the finding of and Kanatas *et al.* (2020) and Arsenijevic *et al.* (2022).

Table 4.1.15 Effect of weed management on weed density (no. m^{-2}) of grasses

	Weed density (no. m^{-2}) of grasses											
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	6.11 (36.80)	5.88 (34.03)	5.99 (35.42)	6.60 (43.07)	6.58 (42.75)	6.59 (42.91)	6.85 (46.44)	6.74 (44.96)	6.80 (45.70)	6.13 (37.03)	5.86 (33.78)	5.99 (35.41)
T_2	5.96 (35.06)	5.80 (33.17)	5.88 (34.11)	5.12 (25.73)	5.06 (25.13)	5.09 (25.43)	5.87 (33.91)	5.64 (31.34)	5.75 (32.62)	5.24 (26.96)	4.94 (23.96)	5.09 (25.46)
T_3	7.67 (58.47)	7.43 (54.67)	7.55 (56.57)	6.27 (38.78)	6.19 (37.80)	6.23 (38.29)	6.46 (41.28)	6.34 (39.77)	6.40 (40.52)	5.62 (31.15)	5.50 (29.74)	5.56 (30.45)
T_4	6.72 (44.61)	6.35 (39.87)	6.53 (42.24)	4.93 (23.86)	4.87 (23.24)	4.90 (23.55)	5.57 (30.56)	5.45 (29.22)	5.51 (29.89)	5.05 (25.01)	4.79 (22.49)	4.92 (23.75)
T_5	7.72 (59.03)	7.47 (55.31)	7.59 (57.17)	6.33 (39.65)	6.37 (40.12)	6.35 (39.88)	6.70 (44.34)	6.47 (41.45)	6.59 (42.89)	5.83 (33.48)	5.78 (32.92)	5.80 (33.20)
T_6	6.75 (45.08)	6.64 (43.62)	6.70 (44.35)	5.20 (26.57)	5.13 (25.87)	5.17 (26.22)	5.96 (35.08)	5.85 (33.70)	5.91 (34.39)	5.43 (29.00)	5.30 (27.61)	5.37 (28.30)
T_7	7.49 (55.66)	7.22 (51.64)	7.36 (53.65)	5.66 (31.50)	5.71 (32.08)	5.68 (31.79)	4.85 (23.05)	4.71 (21.73)	4.78 (22.39)	4.31 (18.07)	4.23 (17.42)	4.27 (17.74)
T_8	7.77 (59.91)	7.48 (55.76)	7.62 (57.84)	9.03 (81.00)	8.84 (77.73)	8.94 (79.36)	9.25 (85.13)	9.14 (83.02)	9.20 (84.07)	8.86 (77.95)	8.69 (75.10)	8.78 (76.52)
SEm±	*0.13*	*0.16*	*0.10*	*0.10*	*0.08*	*0.06*	*0.10*	*0.09*	*0.07*	*0.05*	*0.05*	*0.04*
CD (P=0.05)	*0.39*	*0.48*	*0.30*	*0.31*	*0.23*	*0.18*	*0.30*	*0.28*	*0.20*	*0.16*	*0.15*	*0.11*

Figures in parenthesis are original values; Data is subjected to square root transformation

4.1.3.2 Effect of weed management treatments on weed density (no. m^{-2}) of broad leaf weeds.

The data on weed density of broad leaf weeds under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.16. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of broad leaf weeds.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (5.72 m^{-2}) for broad leaf weeds whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (4.44 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (4.72 m^{-2} and 3.83 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 8.26 m^{-2}, 40 DAS- 8.84 m^{-2}, 60 DAS- 9.45 m^{-2} and at harvest- 8.60 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Priya *et al.* (2009), Bali *et al.* (2016) and Anand *et al.* (2020)

4.1.3.3 Effect of weed management treatments on weed density (no. m^{-2}) of sedges.

The data on weed density of sedges under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.17. The perusal of data revealed that there was significant difference on weed density among the treatments and cause significant reduction in the density of sedges.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (1.71 m^{-2}) for sedges whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (1.66 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (1.48 m^{-2} and 1.46 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 2.68 m^{-2}, 40 DAS- 3.01 m^{-2}, 60 DAS- 3.23

Table 4.1.16 Effect of weed management on weed density (no. m^{-2}) of broad leaf weeds

Weed density (no. m^{-2}) of broad leaf weeds												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	5.92 (34.60)	5.67 (31.71)	5.80 (33.15)	6.83 (46.21)	6.78 (45.45)	6.81 (45.83)	7.84 (61.02)	7.77 (59.92)	7.80 (60.47)	6.93 (47.49)	6.83 (46.12)	6.88 (46.80)
T_2	5.83 (33.54)	5.62 (31.04)	5.72 (32.29)	4.59 (20.55)	4.54 (20.08)	4.56 (20.32)	6.22 (38.18)	6.10 (36.73)	6.16 (37.46)	5.36 (28.23)	5.20 (26.57)	5.28 (27.40)
T_3	8.27 (67.91)	8.19 (66.50)	8.23 (67.21)	5.91 (34.46)	5.83 (33.52)	5.87 (33.99)	6.56 (42.56)	6.48 (41.50)	6.52 (42.03)	5.50 (29.79)	5.43 (29.01)	5.47 (29.40)
T_4	6.92 (47.47)	6.72 (44.66)	6.82 (46.07)	4.47 (19.52)	4.41 (18.92)	4.44 (19.22)	5.40 (28.69)	5.23 (26.92)	5.32 (27.80)	4.29 (17.90)	4.11 (16.41)	4.20 (17.15)
T_5	8.28 (68.25)	8.20 (66.70)	8.24 (67.48)	6.04 (35.97)	5.95 (34.88)	5.99 (35.42)	6.71 (44.55)	6.65 (43.67)	6.68 (44.11)	5.80 (33.11)	5.68 (31.79)	5.74 (32.45)
T_6	7.08 (49.73)	6.80 (45.75)	6.94 (47.74)	4.73 (21.90)	4.67 (21.35)	4.70 (21.63)	5.57 (30.54)	5.45 (29.27)	5.51 (29.91)	4.60 (20.64)	4.49 (19.66)	4.54 (20.15)
T_7	8.24 (67.65)	8.15 (65.92)	8.19 (66.78)	6.20 (37.93)	6.13 (37.03)	6.16 (37.48)	4.76 (22.20)	4.67 (21.35)	4.72 (21.78)	3.90 (14.78)	3.76 (13.63)	3.83 (14.20)
T_8	8.31 (68.52)	8.22 (67.06)	8.26 (67.79)	8.86 (77.97)	8.81 (77.18)	8.84 (77.58)	9.48 (89.38)	9.42 (88.15)	9.45 (88.76)	8.63 (73.98)	8.57 (72.88)	8.60 (73.43)
SEm±	*0.21*	*0.07*	*0.11*	*0.06*	*0.06*	*0.04*	*0.09*	*0.11*	*0.07*	*0.09*	*0.09*	*0.06*
CD (P=0.05)	*0.65*	*0.22*	*0.33*	*0.19*	*0.18*	*0.13*	*0.27*	*0.35*	*0.21*	*0.26*	*0.28*	*0.18*

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.17 Effect of weed management on weed density (no. m^{-2}) of sedges

Weed density (no. m^{-2}) of sedges												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	1.75 (2.57)	1.70 (2.40)	1.73 (2.49)	2.35 (5.04)	2.31 (4.84)	2.33 (4.94)	2.43 (5.42)	2.40 (5.25)	2.41 (5.34)	2.29 (4.76)	2.28 (4.70)	2.29 (4.73)
T_2	1.74 (2.52)	1.69 (2.35)	1.71 (2.43)	1.69 (2.36)	1.68 (2.33)	1.68 (2.35)	2.10 (3.91)	2.08 (3.82)	2.09 (3.87)	2.08 (3.83)	2.05 (3.69)	2.06 (3.76)
T_3	2.70 (6.81)	2.63 (6.40)	2.66 (6.60)	1.89 (3.06)	1.87 (3.02)	1.88 (3.04)	1.94 (3.25)	1.93 (3.21)	1.93 (3.23)	1.91 (3.16)	1.88 (3.02)	1.90 (3.09)
T_4	2.31 (4.85)	2.25 (4.58)	2.28 (4.72)	1.66 (2.27)	1.66 (2.25)	1.66 (2.26)	1.77 (2.65)	1.75 (2.56)	1.76 (2.60)	1.73 (2.51)	1.71 (2.42)	1.72 (2.46)
T_5	2.71 (6.83)	2.64 (6.46)	2.67 (6.64)	1.90 (3.13)	1.90 (3.14)	1.90 (3.13)	2.07 (3.77)	2.05 (3.69)	2.06 (3.73)	2.04 (3.65)	2.02 (3.58)	2.03 (3.62)
T_6	2.33 (4.93)	2.27 (4.68)	2.30 (4.81)	1.81 (2.76)	1.80 (2.74)	1.80 (2.75)	1.83 (2.86)	1.79 (2.74)	1.81 (2.80)	1.80 (2.75)	1.78 (2.68)	1.79 (2.72)
T_7	2.64 (6.53)	2.61 (6.35)	2.63 (6.44)	2.04 (3.67)	2.03 (3.63)	2.04 (3.65)	1.48 (1.69)	1.47 (1.66)	1.48 (1.68)	1.47 (1.68)	1.45 (1.61)	1.46 (1.64)
T_8	2.71 (6.85)	2.64 (6.48)	2.68 (6.66)	3.02 (8.64)	3.00 (8.47)	3.01 (8.56)	3.24 (9.98)	3.21 (9.84)	3.23 (9.91)	3.19 (9.67)	3.17 (9.57)	3.18 (9.62)
SEm±	*0.06*	*0.05*	*0.04*	*0.06*	*0.06*	*0.04*	*0.03*	*0.07*	*0.04*	*0.03*	*0.02*	*0.02*
CD (P=0.05)	*0.17*	*0.16*	*0.11*	*0.19*	*0.19*	*0.13*	*0.08*	*0.23*	*0.12*	*0.10*	*0.07*	*0.06*

Figures in parenthesis are original values; Data is subjected to square root transformation

m^{-2} and at harvest- 3.18 m^{-2}) among the treatments due to more weeds as compared to other treatment. Similar finding was observed by Dhaker *et al*. (2015) and Carkner and Entz (2017).

4.1.3.4 Effect of weed management treatments on total weed density (no. m^{-2}).

The data on total weed density under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.18 and Fig 4.1. The perusal of data revealed that there was significant difference on total weed density among the treatments and cause significant reduction in the density of total weed.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed density (8.33 m^{-2}) whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest weed density (6.75 m^{-2}). At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest weed density (6.80 m^{-2} and 5.84 m^{-2}) among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest weed density (20 DAS- 11.52 m^{-2}, 40 DAS- 12.88 m^{-2}, 60 DAS- 13.54 m^{-2} and at harvest- 12.65 m^{-2}) among the treatments due to more weeds as compared to other treatment. Pendimethalin use as a pre-emergence herbicide *fb* IC at 30 days after sowing may have contributed lowest weed density to this by preventing cell proliferation and elongation in weed which prevented weed seeds from sprouting. The weed density under T_8 under weedy check constantly increased during the experimental year; this could be because no chemicals treatment was administered. Furthermore, during the critical period of weed competition, efficient weed control through weed management practices may be the cause. Similar finding was observed by Kumar *et al*. (2016), Roy *et al*. (2023) and Meena *et al*. (2022).

4.1.4 Dry weight of weeds

4.1.4.1 Effect of weed management treatments on total dry weight of grasses (g. m^{-2}).

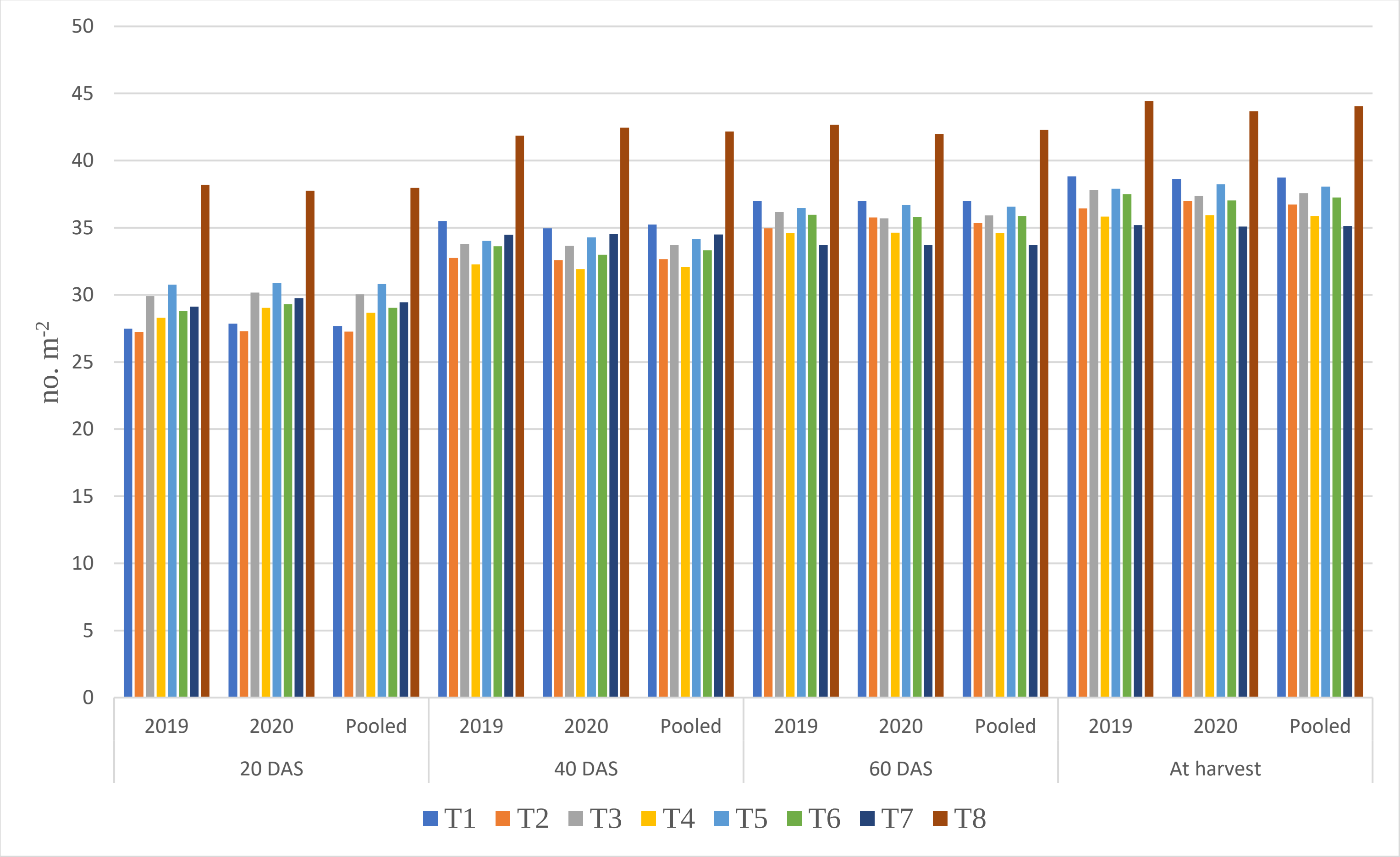
The data on total dry weight of grass under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.19. The perusal of data revealed

Table 4.1.18 Effect of weed management on total weed density (no. m^{-2})

Total weed density (no. m^{-2})												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	8.63 (74.0)	8.28 (68.1)	8.46 (71.1)	9.74 (94.3)	9.67 (93.1)	9.70 (93.7)	10.65 (112.9)	10.52 (110.1)	10.58 (111.5)	9.47 (89.3)	9.22 (84.6)	9.35 (86.9)
T_2	8.46 (71.1)	8.19 (66.6)	8.33 (68.8)	7.01 (48.6)	6.93 (47.5)	6.97 (48.1)	8.75 (76.0)	8.51 (71.9)	8.63 (74.0)	7.71 (59.0)	7.40 (54.2)	7.56 (56.6)
T_3	11.56 (133.2)	11.32 (127.6)	11.44 (130.4)	8.76 (76.3)	8.65 (74.3)	8.71 (75.3)	9.36 (87.1)	9.22 (84.5)	9.29 (85.8)	8.04 (64.1)	7.89 (61.8)	7.96 (62.9)
T_4	9.87 (96.9)	9.47 (89.1)	9.67 (93.0)	6.79 (45.7)	6.70 (44.4)	6.75 (45.0)	7.90 (61.9)	7.69 (58.7)	7.80 (60.3)	6.78 (45.4)	6.47 (41.3)	6.62 (43.4)
T_5	11.60 (134.1)	11.36 (128.5)	11.48 (131.3)	8.90 (78.8)	8.87 (78.1)	8.88 (78.4)	9.65 (92.7)	9.45 (88.8)	9.55 (90.7)	8.41 (70.2)	8.29 (68.3)	8.35 (69.3)
T_6	10.01 (99.7)	9.72 (94.0)	9.87 (96.9)	7.19 (51.2)	7.10 (50.0)	7.15 (50.6)	8.30 (68.5)	8.14 (65.7)	8.22 (67.1)	7.27 (52.4)	7.10 (50.0)	7.19 (51.2)
T_7	11.41 (129.8)	11.15 (123.9)	11.28 (126.9)	8.58 (73.1)	8.56 (72.7)	8.57 (72.9)	6.88 (46.9)	6.72 (44.7)	6.80 (45.8)	5.92 (34.5)	5.76 (32.7)	5.84 (33.6)
T_8	11.65 (135.3)	11.39 (129.3)	11.52 (132.3)	12.97 (167.6)	12.80 (163.4)	12.88 (165.5)	13.60 (184.5)	13.47 (181.0)	13.54 (182.8)	12.73 (161.6)	12.57 (157.6)	12.65 (159.6)
SEm±	*0.17*	*0.12*	*0.10*	*0.09*	*0.06*	*0.05*	*0.11*	*0.10*	*0.08*	*0.08*	*0.06*	*0.05*
CD (P=0.05)	*0.52*	*0.35*	*0.30*	*0.26*	*0.17*	*0.15*	*0.34*	*0.31*	*0.22*	*0.23*	*0.18*	*0.14*

Figures in parenthesis are original values; Data is subjected to square root transformation

Fig. 4.1 Effect of weed management on total weed density (no. m^{-2})



that there was significant difference on total dry weight of grass among the treatments and cause significant reduction in the density of total weed.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed dry weight of grass (1.96 g m^{-2}) whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest dry weight (3.59 g m^{-2}) of grass. At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest dry weight (3.40 g m^{-2} and 2.79 g m^{-2}) of grass among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest dry weight (20 DAS- 2.53 g m^{-2}, 40 DAS- 5.07 g m^{-2}, 60 DAS- 5.45 g m^{-2} and at harvest- 4.81 g m^{-2}) of grass among the treatments due to more weeds as compared to other treatment. This was due to the lower weed population seen under these treatments, which might be attributed to effective weed control at an early stage by herbicide application and afterwards hand weeding. These findings were substantiated by Chandraker and Paikra (2015) and Daramola *et al*. (2018) and Patil *et al*. (2018).

4.1.4.2 Effect of weed management treatments on total dry weight of broad leaf (g. m^{-2}).

The data on total dry weight of broad leaf under different treatments recorded at 20, 40, 60 and at harvest are presented in Table 4.1.20. The perusal of data revealed that there was significant difference on total dry weight of broad leaf among the treatments and cause significant reduction in the density of total weed.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed dry weight of broad leaf (1.64 g m^{-2}) whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest dry weight (4.19 g m^{-2}) of broad leaf. At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest dry weight (3.52 g m^{-2} and 3.22 g m^{-2}) of broad leaf among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest dry weight (20 DAS- 2.64 g m^{-2}, 40

Table 4.1.19 Effect of weed management on total dry weight of grasses (g m^{-2})

Total dry weight of grasses (g m^{-2})												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	2.02 (3.59)	1.99 (3.45)	2.00 (3.52)	4.27 (17.82)	4.21 (17.26)	4.24 (17.54)	4.45 (19.36)	4.41 (18.98)	4.43 (19.17)	4.06 (15.97)	3.72 (13.37)	3.89 (14.67)
T_2	1.97 (3.40)	1.94 (3.29)	1.96 (3.34)	3.67 (12.96)	3.63 (12.67)	3.65 (12.82)	4.07 (16.09)	4.04 (15.84)	4.06 (15.97)	3.58 (12.33)	3.39 (11.08)	3.48 (11.70)
T_3	2.55 (6.03)	2.45 (5.53)	2.50 (5.78)	3.94 (15.03)	3.88 (14.59)	3.91 (14.81)	4.16 (16.82)	4.09 (16.25)	4.13 (16.54)	3.90 (14.71)	3.78 (13.80)	3.84 (14.26)
T_4	2.30 (4.78)	2.23 (4.49)	2.26 (4.63)	3.62 (12.60)	3.57 (12.26)	3.59 (12.43)	3.97 (15.25)	3.87 (14.53)	3.92 (14.89)	3.25 (10.10)	3.09 (9.11)	3.17 (9.61)
T_5	2.58 (6.17)	2.47 (5.62)	2.53 (5.89)	3.96 (15.18)	3.89 (14.64)	3.92 (14.91)	4.16 (16.78)	4.09 (16.19)	4.12 (16.49)	3.88 (14.54)	3.70 (13.20)	3.79 (13.87)
T_6	2.34 (4.99)	2.25 (4.57)	2.30 (4.78)	3.68 (13.07)	3.64 (12.73)	3.66 (12.90)	4.03 (15.72)	3.93 (14.93)	3.98 (15.33)	3.53 (12.01)	3.39 (11.00)	3.46 (11.50)
T_7	2.48 (5.67)	2.39 (5.23)	2.44 (5.45)	3.99 (15.39)	3.91 (14.81)	3.95 (15.10)	3.41 (11.12)	3.39 (10.98)	3.40 (11.05)	2.81 (7.41)	2.77 (7.17)	2.79 (7.29)
T_8	2.58 (6.14)	2.48 (5.67)	2.53 (5.91)	5.09 (25.41)	5.06 (25.08)	5.07 (25.24)	5.47 (29.42)	5.42 (28.92)	5.45 (29.17)	4.89 (23.49)	4.72 (21.81)	4.81 (22.65)
SEm±	*0.05*	*0.06*	*0.04*	*0.09*	*0.06*	*0.06*	*0.08*	*0.06*	*0.05*	*0.12*	*0.11*	*0.08*
CD (P=0.05)	*0.14*	*0.18*	*0.11*	*0.28*	*0.19*	*0.16*	*0.25*	*0.19*	*0.15*	*0.37*	*0.35*	*0.24*

Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.20 Effect of weed management on total dry weight of broad leaf (g m^{-2})

Total dry weight of broad leaf (g m^{-2})												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	1.66 (2.25)	1.65 (2.21)	1.65 (2.23)	4.77 (23.04)	4.91 (21.49)	4.84 (22.26)	5.97 (35.14)	5.68 (31.76)	5.82 (33.45)	5.45 (29.26)	5.35 (28.15)	5.40 (28.70)
T$_2$	1.65 (2.21)	1.64 (2.18)	1.64 (2.19)	4.40 (15.89)	4.86 (14.44)	4.63 (15.16)	4.67 (21.35)	4.35 (18.74)	4.51 (20.05)	4.21 (17.64)	4.09 (16.38)	4.15 (17.01)
T$_3$	2.62 (6.38)	2.63 (6.40)	2.62 (6.39)	4.37 (18.93)	4.51 (16.97)	4.44 (17.95)	5.71 (32.12)	5.43 (28.96)	5.57 (30.54)	5.36 (28.26)	5.22 (26.78)	5.29 (27.52)
T$_4$	2.18 (4.26)	2.18 (4.27)	2.18 (4.27)	4.05 (15.29)	4.33 (13.69)	4.19 (14.49)	4.34 (18.37)	3.94 (15.25)	4.14 (16.81)	4.01 (15.75)	3.80 (14.01)	3.90 (14.88)
T$_5$	2.63 (6.44)	2.63 (6.42)	2.63 (6.43)	4.85 (19.34)	4.91 (18.56)	4.88 (18.95)	5.58 (30.61)	5.22 (26.83)	5.40 (28.72)	5.33 (27.99)	5.01 (24.60)	5.17 (26.30)
T$_6$	2.19 (4.31)	2.19 (4.32)	2.19 (4.31)	4.44 (18.66)	4.65 (16.16)	4.55 (17.41)	4.53 (20.09)	4.15 (16.89)	4.34 (18.49)	4.19 (17.19)	4.06 (15.99)	4.12 (16.59)
T$_7$	2.61 (6.34)	2.62 (6.35)	2.62 (6.34)	3.97 (21.85)	4.24 (19.76)	4.10 (20.81)	3.73 (13.46)	3.30 (10.76)	3.52 (12.11)	3.31 (10.86)	3.13 (9.52)	3.22 (10.19)
T$_8$	2.64 (6.47)	2.63 (6.44)	2.64 (6.45)	6.02 (35.78)	6.21 (33.96)	6.12 (34.87)	7.17 (50.92)	6.77 (45.29)	6.97 (48.11)	6.58 (42.79)	6.28 (39.00)	6.43 (40.90)
SEm±	*0.01*	*0.01*	*0.01*	*0.14*	*0.09*	*0.08*	*0.09*	*0.28*	*0.14*	*0.28*	*0.16*	*0.16*
CD (P=0.05)	*0.03*	*0.04*	*0.02*	*0.41*	*0.27*	*0.23*	*0.27*	*0.84*	*0.42*	*0.84*	*0.48*	*0.46*

Figures in parenthesis are original values; Data is subjected to square root transformation

DAS- 6.12 g m^{-2}, 60 DAS-6.97 g m^{-2} and at harvest- 6.43 g m^{-2}) of broad leaf among the treatments due to more weeds as compared to other treatment. This might be attributed to the reduction in the overall number of total weeds and the decrease in lower biomass during the growth period which was triggered by the herbicide application of Imazethapyr followed by hand weeding. This was congruent with what the finding of Rao *et al*. (2018) and Chaudhari *et al*. (2020).

4.1.4.3 Effect of weed management treatments on total dry weight of sedges (g. m^{-2}).

The data on total dry weight of sedges under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.21. The perusal of data revealed that there was significant difference on total dry weight of sedges among the treatments and cause significant reduction in the density of total weed.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest weed dry weight of sedges (1.05 g m^{-2}) whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the lowest dry weight (1.32 g m^{-2}) of sedges. At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest dry weight (1.19 g m^{-2} and 1.10 g m^{-2}) of sedges among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest dry weight (20 DAS- 1.29 g m^{-2}, 40 DAS- 2.15 g m^{-2}, 60 DAS- 2.58 g m^{-2} and at harvest- 2.37 g m^{-2}) of sedges among the treatments due to more weeds as compared to other treatment. This may be due to Pendimethalin's broad spectrum inhibited cell division and elongation, killing weeds. Imazethapyr, which inhibited three branched-chain amino acids, resulted in a lower weed count and, consequently, a lower weed dry weight of sedges. Similar finding was observed by Gupta *et al*. (2016), Parmar *et al*. (2022) and Patel *et al*. (2023).

4.1.4.4 Effect of weed management treatments on total dry weight of weeds (g. m^{-2}).

The perusal of data on total dry weight of weeds under different treatments recorded at 20, 40, 60 DAS and at harvest are presented in Table 4.1.22 and

Fig. 4.2. The data revealed that there was significant difference on total dry weight of weeds among the treatments and cause significant reduction in the density of total weed.

At 20 DAS, treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted the lowest total dry weight of weeds (2.58 g m^{-2}). In contrast, in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) had the lowest total dry weight (5.35 g m^{-2}) of weeds. At 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted the lowest total dry weight (4.95 g m^{-2} and 4.30 g m^{-2}) of weeds among the weed control treatments. In all the stages, T_8 (unweeded control) resulted the highest total dry weight (20 DAS- 5.91 g m^{-2}, 40 DAS-13.59 g m^{-2}, 60 DAS- 14.57 g m^{-2} and at harvest- 17.07 g m^{-2}) of weeds among the treatments due to more weeds as compared to other treatment. This may be the result of weed control having a rapid knock-down impact and suppressing grasses, sedges, and broad-leaved weeds early in crop growth. Similar findings are in close conformity with conformity as Khazi *et al.* (2017), Singh *et al.* (2019) and Madhu *et al.* (2022).

4.1.5 Effect of weed management treatments on weed control efficiency (%).

By comparing the weed dry weight at harvest to unweeded control, the effectiveness of different weed control methods was calculated for weed control efficiency. Data on the effectiveness of weed control efficiency influenced by the integrated weed management treatment are shown in Table 4.1.23 and in Fig. 4.3.

At 20 DAS, the maximum weed control efficiency (54.48 %) was observed in the treatment T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS). whereas in 40 DAS T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) resulted the maximum weed control efficiency (56.15 %). However, at 60 DAS and at harvest T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) resulted maximum weed control efficiency (71.15 % and 72.42 %) among all the weed control treatments. Contrary to it, the lowest weed control efficiency (WCE) was observed on 20 DAS was observed at T_5 (Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} (20 DAS),

Table 4.1.21 Effect of weed management on total dry weight of sedges (g m^{-2})

Total dry weight sedges (g m^{-2})												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	1.10 (0.72)	1.04 (0.59)	1.07 (0.66)	1.84 (2.88)	1.83 (2.85)	1.83 (2.86)	2.22 (4.41)	2.18 (4.24)	2.20 (4.33)	2.08 (3.83)	1.92 (3.18)	2.00 (3.51)
T_2	1.09 (0.70)	1.01 (0.52)	1.05 (0.61)	1.36 (1.37)	1.32 (1.24)	1.34 (1.31)	1.60 (2.07)	1.54 (1.87)	1.57 (1.97)	1.45 (1.59)	1.32 (1.25)	1.38 (1.42)
T_3	1.29 (1.16)	1.28 (1.13)	1.28 (1.15)	1.73 (2.49)	1.71 (2.44)	1.72 (2.47)	2.09 (3.93)	2.05 (3.70)	2.07 (3.82)	1.74 (2.54)	1.66 (2.25)	1.70 (2.40)
T_4	1.24 (1.03)	1.10 (0.70)	1.17 (0.87)	1.34 (1.31)	1.30 (1.20)	1.32 (1.25)	1.44 (1.58)	1.39 (1.45)	1.42 (1.51)	1.21 (0.95)	1.18 (0.89)	1.19 (0.92)
T_5	1.29 (1.17)	1.28 (1.13)	1.28 (1.15)	1.77 (2.63)	1.75 (2.57)	1.76 (2.60)	1.99 (3.52)	1.98 (3.41)	1.99 (3.46)	1.69 (2.37)	1.63 (2.18)	1.66 (2.27)
T_6	1.25 (1.06)	1.12 (0.77)	1.19 (0.92)	1.39 (1.45)	1.36 (1.37)	1.38 (1.41)	1.55 (1.92)	1.45 (1.61)	1.50 (1.77)	1.51 (1.79)	1.48 (1.70)	1.50 (1.75)
T_7	1.29 (1.16)	1.27 (1.11)	1.28 (1.13)	1.80 (2.74)	1.78 (2.68)	1.79 (2.71)	1.20 (0.94)	1.18 (0.89)	1.19 (0.92)	1.12 (0.76)	1.08 (0.66)	1.10 (0.71)
T_8	1.29 (1.18)	1.28 (1.14)	1.29 (1.16)	2.17 (4.19)	2.13 (4.05)	2.15 (4.12)	2.58 (6.18)	2.57 (6.10)	2.58 (6.14)	2.38 (5.17)	2.36 (5.08)	2.37 (5.13)
SEm±	*0.04*	*0.04*	*0.03*	*0.06*	*0.05*	*0.04*	*0.10*	*0.04*	*0.05*	*0.05*	*0.05*	*0.03*
CD (P=0.05)	*0.12*	*0.12*	*0.08*	*0.18*	*0.16*	*0.12*	*0.30*	*0.11*	*0.15*	*0.14*	*0.15*	*0.10*

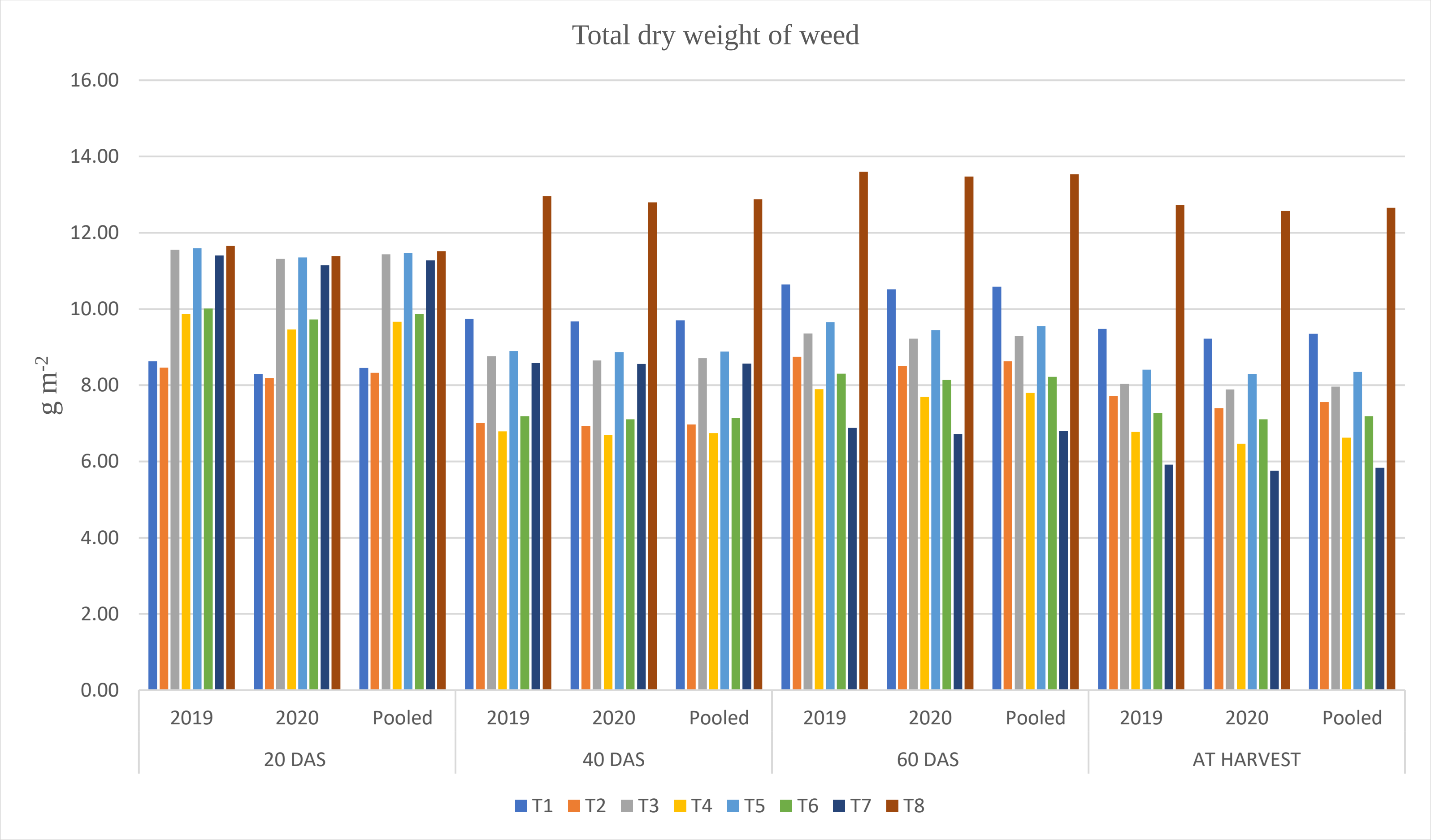
Figures in parenthesis are original values; Data is subjected to square root transformation

Table 4.1.22 Effect of weed management on total dry weight of weeds (g m^{-2})

Total dry weight of weeds (g m^{-2})												
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	2.66 (6.56)	2.60 (6.25)	2.63 (6.41)	6.65 (43.74)	6.49 (41.59)	6.57 (42.67)	7.71 (58.90)	7.45 (54.98)	7.58 (56.94)	7.04 (49.05)	6.72 (44.70)	6.88 (46.88)
T$_2$	2.61 (6.31)	2.54 (5.98)	2.58 (6.15)	5.54 (30.21)	5.37 (28.35)	5.46 (29.28)	6.32 (39.52)	6.06 (36.45)	6.19 (37.99)	5.65 (31.56)	5.40 (28.71)	5.52 (30.14)
T$_3$	3.75 (13.56)	3.68 (13.06)	3.72 (13.31)	6.08 (36.46)	5.87 (33.99)	5.97 (35.23)	7.31 (52.87)	7.03 (48.92)	7.17 (50.90)	6.78 (45.52)	6.58 (42.84)	6.68 (44.18)
T$_4$	3.25 (10.07)	3.16 (9.46)	3.20 (9.77)	5.45 (29.20)	5.26 (27.15)	5.35 (28.18)	5.97 (35.20)	5.62 (31.23)	5.80 (33.21)	5.22 (26.80)	4.94 (24.01)	5.08 (25.40)
T$_5$	3.78 (13.77)	3.70 (13.16)	3.74 (13.47)	6.13 (37.15)	6.02 (35.77)	6.08 (36.46)	7.17 (50.91)	6.85 (46.43)	7.01 (48.67)	6.74 (44.90)	6.36 (39.98)	6.55 (42.44)
T$_6$	3.30 (10.36)	3.19 (9.66)	3.24 (10.01)	5.80 (33.18)	5.54 (30.25)	5.67 (31.72)	6.18 (37.73)	5.82 (33.43)	6.00 (35.58)	5.60 (30.99)	5.40 (28.68)	5.50 (29.84)
T$_7$	3.70 (13.16)	3.63 (12.68)	3.66 (12.92)	6.36 (39.98)	6.14 (37.25)	6.25 (38.62)	5.10 (25.52)	4.79 (22.63)	4.95 (24.08)	4.39 (19.03)	4.21 (17.35)	4.30 (18.19)
T$_8$	3.78 (13.79)	3.71 (13.25)	3.74 (13.52)	8.12 (65.37)	7.97 (63.09)	8.05 (64.23)	9.33 (86.52)	8.99 (80.31)	9.16 (83.42)	8.48 (71.45)	8.15 (65.89)	8.31 (68.67)
SEm±	*0.03*	*0.04*	*0.03*	*0.11*	*0.07*	*0.07*	*0.09*	*0.19*	*0.11*	*0.22*	*0.14*	*0.13*
CD (P=0.05)	*0.10*	*0.13*	*0.08*	*0.35*	*0.20*	*0.19*	*0.28*	*0.58*	*0.31*	*0.68*	*0.41*	*0.38*

Figures in parenthesis are original values; Data is subjected to square root transformation

Fig. 4.2 Effect of weed management on total dry weight of weeds (g m^{-2})



meanwhile at 40 DAS, 60 DAS and at harvest WCE was recorded under pre-emergence application of Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} (T$_1$) 33.59 %, 31.72 % and 31.41 % respectively during investigation.

This may be the result of pre-emergence treatments with pendimethalin 30 EC and imazethapyr 10 SL that suppressed weed germination and growth. The latter treatment may have also inhibited weed growth by killing off weeds through a variety of metabolic activities and by preventing weeds and crops from competing with each other for resources. The interculture operation at 30 DAS successfully suppressed the second flush of weeds. These generally constitute the main contributors to weeds acquiring reduced dry weight and, consequently, higher efficacy in weed control. This result has been recounted by Kundu *et al*, (2011), Patel *et al,* (2019) and Meena *et al,* (2020).

4..1.6 Effect of weed management treatments on weed index (%).

The efficacy of weed management treatments varies depending on the nature and procedure of weed control; the weed index displays the percentage reduction in yield loss caused by weeds due to competitional stress under different treatments when compared to weed-free plots. The perusal of data on the weed control index influenced by the integrated weed management treatment are shown in Table 4.1.24 and in Fig. 4.4.

The finding clearly show that maximum reduction in yield (51.51%) happened in plots with uncontrolled weeds, extensive infestation, and severe weed competition throughout the crop season (unweeded control). However, T$_4$ (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) reduce down the yield to the extent of 2.90 % followed by T$_2$ (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) which reduce yield by 4.65%. compared to the other treatments (T$_3$, T$_6$, T$_1$ and T$_5$) higher weed index (15.00% to 25.60%) was observed. These results were in conformity with the findings Prachand *et al*. (2015), Gupta *et al*. (2017) and Rupareliya *et al*. (2020).

Table 4.1.23 Effect of weed management on weed control efficiency (%)

	Weed control efficiency (%)											
Treatments	***20 DAS***			***40 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	52.42	52.85	52.63	33.10	34.08	33.59	31.90	31.53	31.72	31.30	31.53	31.41
T_2	54.25	54.70	54.48	53.78	55.06	54.42	54.32	54.63	54.48	55.48	54.63	55.06
T_3	1.61	1.39	1.50	44.24	46.13	45.18	38.87	39.09	38.98	36.05	39.09	37.57
T_4	26.93	28.42	27.67	55.33	56.97	56.15	59.31	61.09	60.20	62.47	61.09	61.78
T_5	0.13	0.43	0.28	43.16	43.31	43.23	41.16	42.17	41.67	37.05	42.17	39.61
T_6	24.83	27.02	25.93	49.23	52.06	50.65	56.39	58.35	57.37	56.57	58.35	57.46
T_7	4.52	4.06	4.29	38.83	40.96	39.89	70.48	71.81	71.15	73.02	71.81	72.42
T_8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sem±	1.56	3.10	1.74	2.16	1.16	1.23	1.33	2.70	1.51	3.70	2.70	2.29
CD at 5%	4.73	9.40	5.03	6.54	3.53	3.55	4.03	8.19	4.36	11.22	8.19	6.63

Table 4.1.24 Effect of weed management on weed index (%) in soybean

Treatments	***Weed index (%)***		
	2019	***2020***	***Pooled***
T_1 : Pendimethalin 30 EC @ 1.0 kg a.i. ha 1 – pre emergence	26.48	21.11	23.80
T_2 : Pendimethalin 30 EC @ 1.0 kg a.i. ha 1 – *fb* IC at 30 DAS	5.30	3.99	4.65
T_3 : Imazethapyr 10 SL @ 100g a.i. ha 1 – post emergence, 20 DAS	17.10	12.90	15.00
T_4 : Imazethapyr 10 SL @ 100g a.i. ha 1 (10 DAS) early post emergence – *fb* IC at 30 DAS	2.49	3.30	2.90
T_5 : Sulfentrazone 48 SC @ 360 g a.i. ha 1 – post emergence, 20 DAS	27.20	24.00	25.60
T_6 : Sulfentrazone48 SC @ 360 g a.i. ha 1 (10 DAS) early post emergence – *fb* IC at 30 DAS	16.48	15.83	16.15
T_7 : IC at 20 DAS fb hand weeding at 40 DAS	0.00	0.00	0.00
T_8 : Unweeded control	49.60	53.42	51.51
Sem±	2.03	4.50	2.47
CD at 5%	6.16	13.65	7.15

Fig. 4.3 Effect of weed management on weed control efficiency (%)

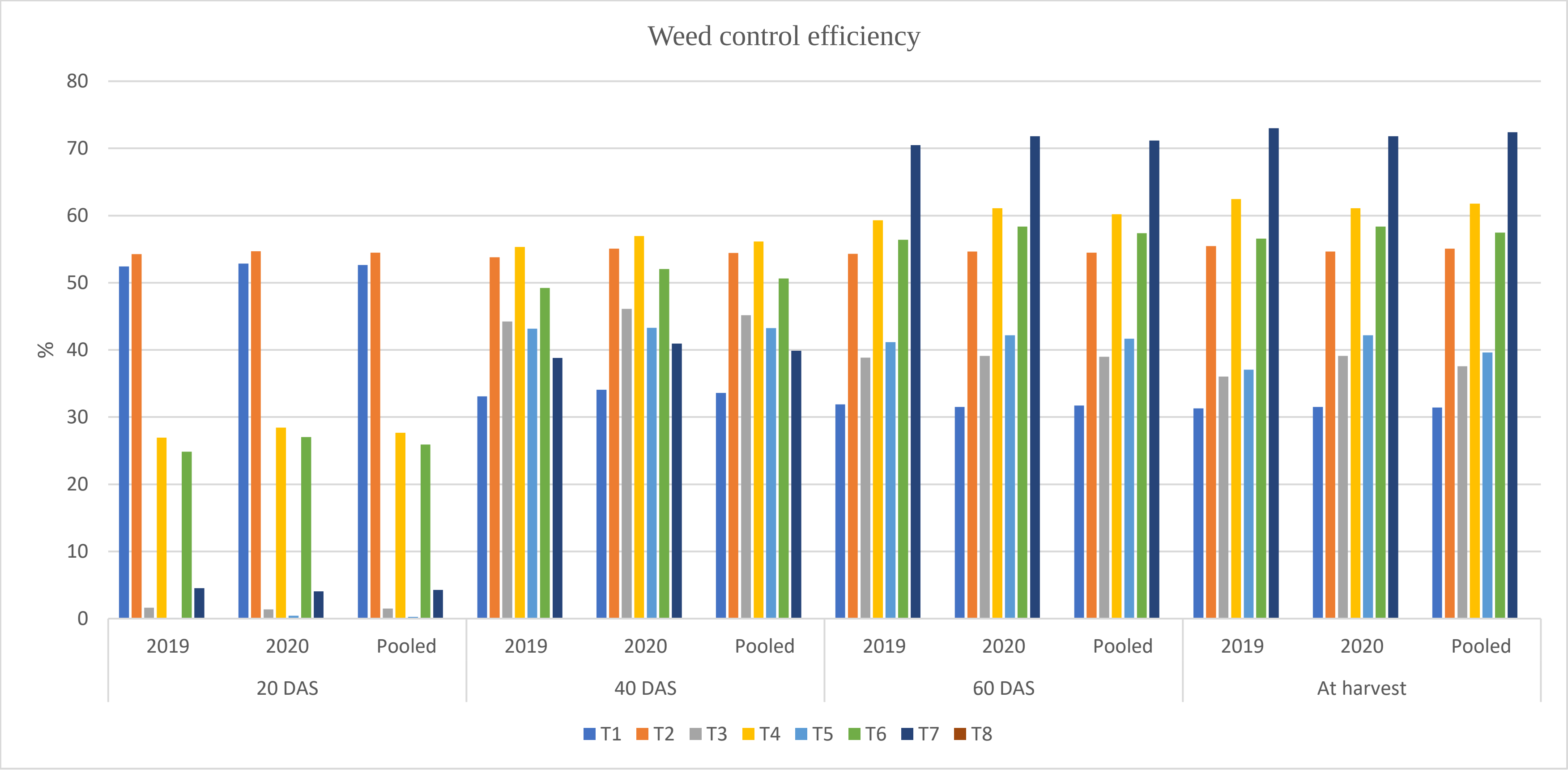
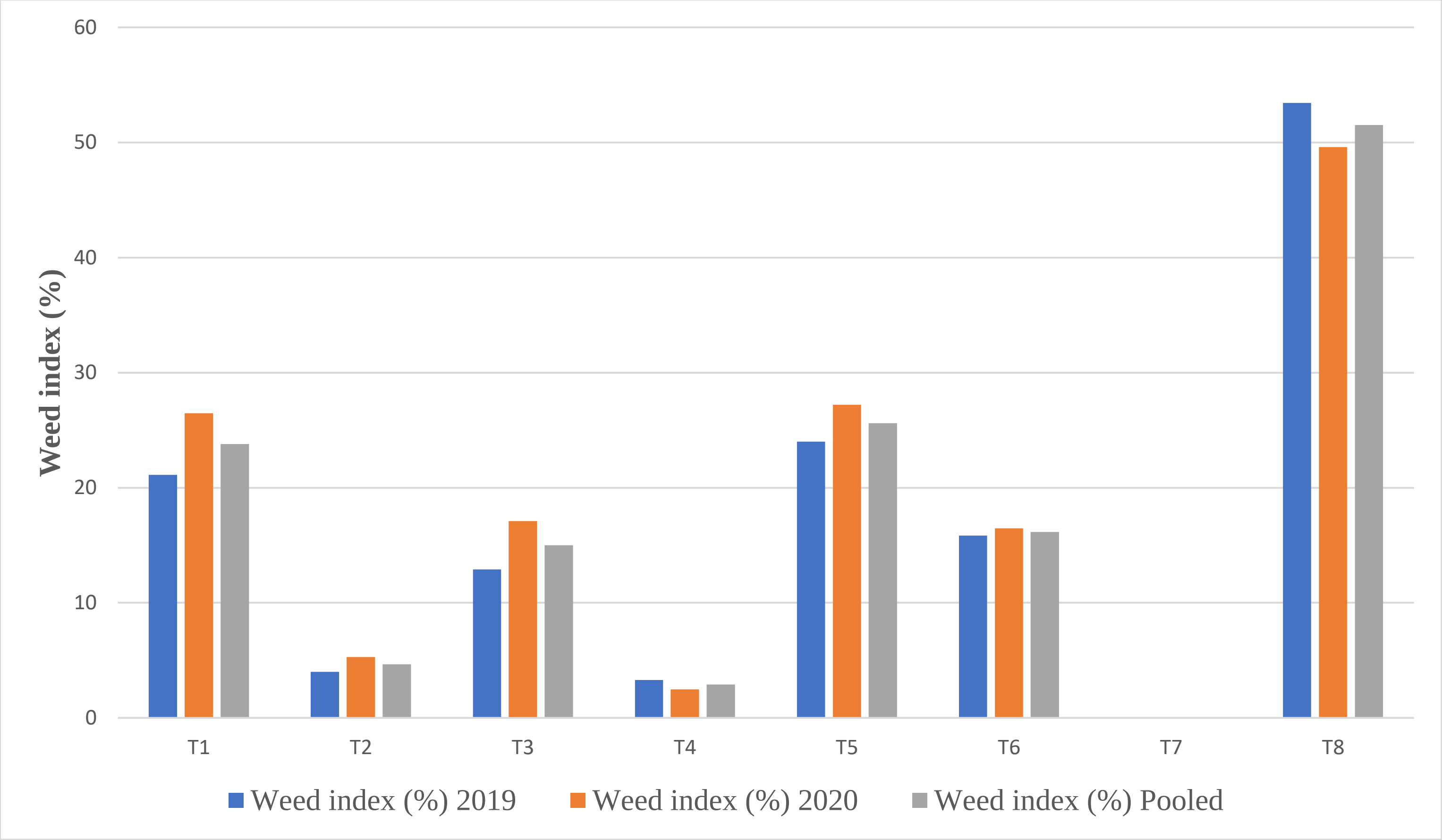


Fig. 4. 4 Effect of weed management on weed index (%) in soybean



4.2 Observation on crop

4.2.1 Growth attributes

4.2.1.1 Plant height:

The data on mean plant height pertaining to different weed management treatments recorded at 30, 60 DAS and at the harvest stage of soybean are presented in table 4.1.25. It is evident from the data that plants were taller during 2020 compared to 2019 at all the stages of observation.

At 30 DAS, pre-emergence application of Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS (T_2) recorded significantly taller plants (25.77 cm) followed by T_7 (IC at 20 DAS *fb* Hand weeding at 40 DAS) (25.24 cm) than the other treatments. At 60 DAS and at harvest, the significantly highest plant height (60.90 and 58.20 cm) was recorded at T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) followed by T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) (58.25 and 56.56 cm) during the years of study. The rest of the weed management practices were statistically at par with each other in both years. However, the shorter plant height (20.56, 46.44 and 43.04 cm) was observed in T_8 (unweeded control) in all crop growth stages. This may be because weeds were successfully controlled during the critical stages of crop growth, increasing the amount of nutrients available and causing photosynthates to accumulate. Moreover, inter-cultivation was combined with the application of a pre- and post-emergence herbicide during the critical crop growth phase. Similar findings are in conformity with the earlier reports of Kumar *et al*. (2008), Chandraker and Paikra (2015) and Lunagariya *et al*. (2021).

4.2.1.2 Number of primary branches per plant.

Observations on the number of primary branches recorded at 30, 60 DAS and at harvest are presented in Table 4.1.26. Different weed management methods significantly influence the number of primary branches per plant at all the stages of observation. At 30 DAS, the highest number of branches plant^{-1} was observed in the application of Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS (T_2) and the lowest primary branches plant^{-1} in T_8 (unweeded control). A similar result was reported by

Table 4.1.25 Effect of weed management on plant height (cm) of soybean (at 30, 60 DAS and at harvest)

Treatments	**Plant height (cm)**								
	30 DAS			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	24.08	23.42	23.75	51.24	52.55	51.93	48.51	49.14	48.82
T_2	25.78	25.76	25.77	54.04	53.56	53.80	52.67	52.76	52.72
T_3	24.16	23.98	24.07	52.45	52.78	52.60	49.10	51.89	50.50
T_4	26.03	24.83	25.43	56.22	60.23	58.25	55.22	57.90	56.56
T_5	22.27	22.39	22.33	52.91	53.74	53.34	49.98	51.95	50.97
T_6	22.39	22.48	22.44	54.38	53.77	54.07	52.71	52.74	52.73
T_7	25.13	25.34	25.24	58.04	63.75	60.90	57.85	58.56	58.20
T_8	20.80	20.32	20.56	44.46	47.81	46.44	41.17	44.90	43.04
SEm±	*0.63*	*0.64*	*0.45*	*2.31*	*1.88*	*1.49*	*1.96*	*1.48*	*1.23*
CD (P=0.05)	*1.90*	*1.93*	*1.29*	*7.01*	*5.70*	*4.32*	*5.93*	*4.49*	*3.55*

Anand *et al*. (2020). However, at 60 and at harvest, T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) was observed to have the highest number of primary branches plant^{-1} followed by T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) and T_2 (Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} [early-post]– *fb* IC at 30 DAS). While the lowest values of number of branches plant^{-1} were found in T_8 (unweeded control) in all crop growth stages. Better weed management might have resulted in reduced crop-weed competition for the growth factors such as light, space, and nutrients, which in turn helped in producing a higher number of primary branches plant^{-1}. The results are in conformity with the findings of Meena *et al*. (2011), Kumar *et al*. (2016) and Ferdous *et al*. (2017).

4.2.1.3 Leaf Area Index.

The observations on Leaf Area Index were recorded at 30 and 60 DAS (Table 4.1.27) and showed significant variation among various treatments, including unweeded control. At 30 DAS, the maximum number of Leaf Area Index on soybeans was recoded in T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS). However, at 60 DAS, there were recorded increases in Leaf Area Index under various treatments. The highest LAI was recorded on T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) followed by the treatment of T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS). All the herbicide treatments registered significantly higher Leaf Area Index than the unweeded control. This may be due to a comparatively weed-free environment by lowering the biomass and density of weeds, which would have encouraged soybeans to grow healthily and create more photosynthetic area, and reflected a higher LAI. The results are in close conformity with the findings of Silva *et al*. (2013) and Patil *et al*. (2018).

4.2.1.4 Dry weight of plant

The dry weight of plants significantly varied as a result of herbicidal treatments for both years, as shown in Table 4.1.28, which records the dry weight of plants recorded at 30 and 60 days after sowing. At 30 DAS, plant dry weight was substantially greater under Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS (1.42 g

Table 4.1.26 Effect of weed management on number of primary branches per plant (at 30, 60 DAS and at harvest)

	Number of primary branches plant^{-1}								
Treatments	***30 DAS***			***60 DAS***			***At harvest***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	1.49	1.51	1.50	3.77	3.47	3.62	3.37	3.56	3.47
T_2	1.87	1.91	1.89	3.92	4.04	3.98	3.82	3.85	3.84
T_3	1.68	1.54	1.61	3.50	3.81	3.66	3.64	3.51	3.58
T_4	1.79	1.72	1.76	4.02	4.12	4.07	3.89	3.96	3.92
T_5	1.28	1.34	1.31	3.78	3.98	3.88	3.65	3.59	3.62
T_6	1.50	1.55	1.52	4.03	4.04	4.04	3.90	3.93	3.92
T_7	1.56	1.75	1.66	4.38	4.31	4.34	4.25	3.96	4.10
T_8	1.20	1.21	1.21	2.59	2.58	2.59	2.40	2.42	2.41
SEm±	*0.14*	*0.13*	*0.09*	*0.22*	*0.19*	*0.15*	*0.20*	*0.16*	*0.13*
CD (P=0.05)	*0.42*	*0.38*	*0.27*	*0.67*	*0.58*	*0.42*	*0.61*	*0.49*	*0.37*

Table 4.1.27 Effect of weed management on leaf area index (LAI) of soybean

Leaf Area Index (LAI)						
Treatments	***30 DAS***			***60 DAS***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	0.47	0.48	0.48	1.90	1.89	1.90
T_2	0.62	0.63	0.62	2.04	2.06	2.05
T_3	0.53	0.54	0.54	1.93	1.96	1.95
T_4	0.62	0.61	0.62	2.31	2.36	2.33
T_5	0.45	0.46	0.46	2.01	2.01	2.01
T_6	0.51	0.52	0.51	2.10	2.08	2.09
T_7	0.59	0.59	0.59	2.32	2.41	2.36
T_8	0.41	0.41	0.41	1.79	1.77	1.78
SEm±	*0.02*	*0.02*	*0.02*	*0.09*	*0.08*	*0.06*
CD (P=0.05)	*0.06*	*0.07*	*0.05*	*0.26*	*0.25*	*0.17*

Table 4.1.28 Effect of weed management on dry weight of plant (g $plant^{-1}$) (at 30 and 60 DAS)

Dry weight of plant (g $plant^{-1}$)						
Treatments	***30 DAS***			***60 DAS***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	1.25	1.33	1.28	10.44	10.49	10.49
T_2	1.43	1.45	1.42	13.15	13.25	13.18
T_3	1.37	1.35	1.36	11.48	11.57	11.52
T_4	1.37	1.38	1.39	14.72	14.78	14.77
T_5	1.29	1.28	1.30	12.52	12.61	12.59
T_6	1.36	1.34	1.34	13.31	13.39	13.37
T_7	1.37	1.35	1.37	14.81	14.84	14.84
T_8	1.09	1.14	1.13	9.26	9.68	9.48
SEm±	*0.06*	*0.05*	*0.04*	*0.66*	*0.59*	*0.44*
CD (P=0.05)	*0.18*	*0.14*	*0.11*	*1.99*	*1.8*	*1.28*

plant^{-1}) followed by T_4, T_3, T_7, T_6, and T_1 over unweed control (1.13 g plant^{-1}). The dry weight of the plant under various treatments varied from 1.28-1.42 g plant^{-1}.

At 60 DAS, the plant dry weight increases sharply for both year in all the treatments varying from 11.52 - 14.84 g plant^{-1}. The significantly higher plant dry weight was observed under the treatment IC at 20 DAS *fb* hand weeding at 40 DAS (14.84 g plant^{-1}) which was at par with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (14.77 g plant^{-1}) was followed by all other treatment except unweed control (9.48 g plant^{-1}).

The highest dry matter accumulation in the crop was probably caused by more effective weed control techniques, despite indications that the lowest dry matter accumulation was observed under the weedy check treatment. Using those methods, the primary crop and weeds are less likely to compete for vital resources like light, nutrients, and moisture. As a result, the application of efficient weed control treatments reduces the total competition between weeds and crops, which significantly improves crop development as shown by an increase in the accumulation of dry matter. This increase in dry matter buildup increases the efficiency of photosynthetic translocation to the sink and has a stream-flow effect on the crop's reproductive structures. These results are consistent with studies on crop growth and yield produced by efficient weed management. These outcomes align with the research conducted by Meena *et al*. (2011), Chaudhari *et al*. (2020), Katoch *et al*. (2023)

4.2.1.5 No. of root nodules per plant:

The data on the number of root nodules per plant as impacted by various treatments has been critically examined and is reported in Table 4.1.29. In both years, at 30 and 60 DAS, observations were made regarding the number of root nodules per plant. The number of root nodules per plant varied significantly according to the treatment variables, as can be seen from a scanning of the data.

Integrated weed management treatment in soybeans was found to have a considerable impact on data regarding the number of root nodules per plant. According to a data analysis, at 30 DAS, Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS (T_2) markedly increased the highest number of root nodules per plant (18.86 plant^{-1}) and this was followed by its counterpart sprayed with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) – Post emergence, *fb* IC at 30 DAS (T_4) noted more root nodules (18.30 plant^{-1}) after emergence. Nonetheless, during the field study, weedy check (T_8) had fewer root nodules per plant (12.92 plant^{-1}).

At 60 DAS, higher number count of root nodules per plant (52.58 plant^{-1}) was observed on T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) followed by the treatment of T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) observed (52.40 plant^{-1}) root nodules per plant. The lowest count of root nodules per plant (24.24 plant^{-1}) was observed on unweed control (T_8).

Their superior effectiveness in removing weeds and reducing their competitiveness against crop plants may be the reason for the increase in soybean yield and its components compared to the weeded treatments. Furthermore, hoeing is crucial for enhancing soil qualities like structure, aeration, water penetration, and nutrient availability. In other words, by reducing weed infestation using interculture, hand weeding or herbicidal treatments, these benefits may be the consequence of less competition for nutrients, water, and light as a result of nutrient intake. These results are consistent with studies of Abdelhamid and El-Metwally (2008) and Meena *et al*. (201l) and Ahirwar *et al*. (2018).

4.2.1.6 No. of fresh and dry weight of nodules per plant.

Data pertaining to fresh weight of nodules plant^{-1} (g plant^{-1}) at 30 and 60 DAS are presented in Table 4.1.30. Upon analyzing two-year polled data (2019-2020), it became apparent that the experiment's years of weed management had a considerable impact on the fresh weight of nodules.

At 30 DAS, the application of T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) resulted in noticeably higher fresh weight and dry weight of nodules (0.23 and 0.12 g plant^{-1}). This was followed by the treatment sprayed with T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS)

Table 4.1.29 Effect of weed management on root nodules plant^{-1} of soybean (at 30 and 60 DAS)

Number of root nodules plant^{-1}						
Treatments	***30 DAS***			***60 DAS***		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	13.56	15.14	14.33	25.89	27.37	26.58
T_2	18.79	18.97	18.86	32.58	33.83	33.15
T_3	15.14	19.09	17.12	28.56	29.82	29.18
T_4	17.47	19.16	18.30	51.85	52.97	52.40
T_5	12.65	12.15	12.35	29.07	30.48	29.75
T_6	14.27	14.88	14.57	41.66	39.50	40.54
T_7	17.52	17.04	17.29	52.13	53.13	52.58
T_8	13.35	12.45	12.92	23.97	24.53	24.24
SEm±	*1.34*	*1.59*	*1.04*	*1.95*	*3.06*	*1.82*
CD (P=0.05)	*4.07*	*4.84*	*3.02*	*5.93*	*9.29*	*5.26*

Table 4.1.30 Effect of weed management on fresh and dry weight of nodules plant^{-1}

Treatments	**Nodules fresh weight plant^{-1} (g)**						**Nodules dry weight plant^{-1} (g)**					
	30 DAS			**60 DAS**			**30 DAS**			**60 DAS**		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	0.15	0.18	0.17	0.17	0.20	0.18	0.04	0.06	0.06	0.05	0.06	0.06
T_2	0.22	0.24	0.23	0.21	0.21	0.21	0.12	0.12	0.12	0.09	0.08	0.08
T_3	0.18	0.20	0.19	0.17	0.21	0.19	0.07	0.07	0.07	0.06	0.07	0.06
T_4	0.20	0.20	0.20	0.22	0.23	0.23	0.07	0.09	0.08	0.10	0.10	0.10
T_5	0.16	0.18	0.17	0.23	0.19	0.21	0.04	0.05	0.04	0.11	0.06	0.08
T_6	0.16	0.19	0.18	0.19	0.24	0.22	0.04	0.06	0.05	0.07	0.10	0.09
T_7	0.18	0.22	0.20	0.24	0.27	0.26	0.09	0.07	0.08	0.14	0.15	0.15
T_8	0.14	0.16	0.15	0.17	0.18	0.17	0.03	0.03	0.03	0.05	0.04	0.05
SEm±	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.00*	*0.01*	*0.01*	*0.01*
CD (P=0.05)	*0.03*	*0.03*	*0.02*	*0.03*	*0.03*	*0.02*	*0.02*	*0.02*	*0.01*	*0.02*	*0.03*	*0.02*

and T_7 (IC at 20 DAS *fb* Hand weeding at 40 DAS) (0.20 and 0.08 g plant^{-1}), respectively and showed their significant superiority over rest of the treatments under investigation. Comparative to this, T_8 (unweed control) produced the least fresh weight of nodules (0.15 and 0.03 g plant^{-1}) as a result of stressful circumstances and a high weed infestation during the crop seasons.

At 60 DAS, it was found that significantly higher fresh and dry weight of nodules (0.26 and 0.15 g plant^{-1}) was recorded under the weed management of T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) and followed by the treatment sprayed with T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) (0.23 and 0.10 g plant^{-1}) and T_6 (Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS) (0.22 and 0.09 g plant^{-1}), respectively due to season long weed free condition. The least fresh weight of nodules (0.17 and 0.05 g plant^{-1}) was produced in T_8 (unweed control).

The application of different weed management has considerably impacted the nodules fresh and dry weight plant^{-1} at 30 and 60 DAS. As the period of weed-free increased, so did the weight of fresh and dry nodules per plant (Mirjha *et al.* 2013). Under investigation highest fresh and dry weight was observed at the treatment at T_4 followed by T_2 and T_7 and a lesser number of nodules fresh and dry weight was observed on T_8 due to severe infestation weeds creating unfeasible condition for nodule formation. The increase in fresh and dry weight of nodule under weed free condition might be due to improvement in rhizosphere aeration that improved soil condition and uptake of nutrients especially nitrogen to initiate the process of root colonization via symbiotic micro-organisms. The results are in close conformity with the findings of Kale *at al.* (2015), Dhayal *et al.* (2022) and Gohil *et al.* (2022).

4.2.1.7 Crop growth rate (g m^{-2} day^{-1})

Crop growth rate pooled data for two years was recorded at 30-60 DAS and 60-90 DAS and harvest and presented in Table 4.1.31.

The observations of crop growth rate at an early 30 to 60 day interval (Table 4.1.30) revealed that higher CGR was recorded (9.91 g m^{-2} day^{-1}) under T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) which was at par (9.93 g m^{-2} day^{-1}) with T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) and was followed by all the treatments (T_6, T_4, T_5, T_6 and T_2) except T_8 unweed control (6.19 g m^{-2} day^{-1}) recorded significantly lower CGR.

At 60-90 DAS, T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) registered a higher CGR (7.99 g m^{-2} day^{-1}) and it was at par (7.94 g m^{-2} day^{-1}) with T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) and was followed by all the treatments (T_2, T_3, T_6, T_1 and T_5). During observation, T_8 (unweeded control) indicated a reduction of lower crop growth rate (4.33 g m^{-2} day^{-1}) at observation.

CGR was found to be higher and reached to its peak between at 30-60 DAS and slightly declined at 60-90 DAS. Variation in crop growth rate attributed due to weed free condition at critical period of crop and enhanced vegetative growth with better source sink relationship to accumulate enough dry matter. This was supported by Jakhar and Sharma (2015), Ghogare *et al.* (2020), Anusha *et al.* (2021) and Bijarnia *et al.* (2023).

Kurrey *et al.* (2016) report the senescence of leaves contributes to the lowered rate of crop growth, perhaps weeds compete with crops for solar radiation and grow more densely during these periods. Weed-free plots exhibited a higher CGR value in soybean, and CGR values increased during 30-60 DAS compared to 60 DAS to harvest

4.2.1.8 Relative growth rate

Relative growth rate pooled data for both the years was recorded at 30-60 DAS and 60-90 DAS presented in Table 4.1.32.

The observations of relative growth rate at an early 30 to 60 day interval (Table 4.1.30) revealed that higher RGR was recorded (0.034 g g^{-1} day^{-1}) under T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS)

Table 4.1.31 Effect of weed management on crop growth rate (CGR) (g m^{-2} day^{-1}) (at 30-60 DAS and 60-90 DAS)

Crop growth rate (CGR) (g m^{-2} day^{-1})						
Treatments	**30-60 DAS**			**60-90 DAS**		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	7.60	7.58	7.59	4.17	4.83	4.47
T$_2$	8.86	8.92	8.87	6.73	6.67	6.68
T$_3$	8.73	8.79	8.75	5.13	4.99	5.07
T$_4$	9.89	9.93	9.91	7.74	8.19	7.94
T$_5$	6.80	6.82	6.83	60.5	6.12	6.10
T$_6$	8.29	8.39	8.35	6.53	6.92	6.71
T$_7$	9.93	9.96	9.93	7.86	8.15	7.99
T$_8$	6.08	6.35	6.19	4.39	4.29	4.33
SEm±	*0.46*	*0.43*	*0.31*	*0.54*	*0.47*	*0.36*
CD (P=0.05)	*1.39*	*1.30*	*0.91*	*1.63*	*1.43*	*1.03*

Table 4.1.32 Effect of weed management on relative growth rate (RGR) (g g^{-1} day^{-1}) (at 30-60 DAS and 60-90 DAS)

Relative growth rate (RGR) (g g^{-1} day^{-1})						
Treatments	**30-60 DAS**			**60-90 DAS**		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	0.034	0.033	0.032	0.006	0.006	0.006
T_2	0.036	0.035	0.033	0.008	0.008	0.008
T_3	0.033	0.033	0.033	0.007	0.007	0.007
T_4	0.034	0.034	0.034	0.008	0.008	0.008
T_5	0.031	0.031	0.031	0.008	0.008	0.008
T_6	0.032	0.032	0.032	0.008	0.008	0.008
T_7	0.034	0.034	0.034	0.009	0.009	0.009
T_8	0.031	0.031	0.031	0.006	0.005	0.006
SEm±	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*	*0.000*
CD (P=0.05)	*0.002*	*0.003*	*0.002*	*0.002*	*0.002*	*0.001*

and (0.034 g g^{-1} day^{-1}) in T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) and was followed by all the treatments (T_2, T_3, T_1 and T_6). Lower RGR (0.031 g g^{-1} day^{-1}) was observed on T_8 (unweed control) and T_5 (Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} – Post emergence, 20 DAS).

At 60-90 DAS, T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) registered a higher RGR (0.009 g g^{-1} day^{-1}) and it was at par (0.008 g g^{-1} day^{-1}) with all the treatments (T_2, T_3, T_4 and T_6). During observation, T_8 (unweeded control) and T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1}) indicated a reduction of lower relative growth rate (0.006 g g^{-1} day^{-1}) at observation.

Tandale and Ubale (2007) reported that according to the pooled data, the highest RGR peaked between 30 and 60 DAS and declined between 60 and 90 DAS till crop harvest. There was a noticeable positive correlation between the RGR and seed yield during 30 and 60 DAS. Decrease in crop-weed and insect competition led to an increase in the growth rate of soybeans. The increased sink size was able to store photosynthates more efficiently, which in turn led to an increase in the accumulation of dry matter and a higher relative growth rate Jakhar and Sharma (2015).

4.2.1.9 Net assimilation rate

Net assimilation rate pooled data for both the years was recorded at 30-60 DAS and 60-90 DAS, presented in Table 4.1.33.

The observations of net assimilation rate at an early 30 to 60 days interval (Table 4.1.33) revealed that higher NAR was recorded (3.38 g m^{-2} day^{-1}) under T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) followed by T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) (3.34 g m^{-2} day^{-1}) and in T_3 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) – Post emergence, 20 DAS) and was followed by all the treatments (T_7, T_6, T_2, T_1 and T_5). Lower NAR (2.89 g m^{-2} day^{-1}) was observed on T_8 (unweed control).

At 60-90 DAS, highest NAR was recorded (1.43 g m^{-2} day^{-1}) T_7 (IC at 20 DAS *fb* hand weeding at 40 DAS) and it was at par by T_4 (Imazethapyr

Table 4.1.33 Effect of weed management on net assimilation rate (NAR) (g m^{-2} day^{-1}) (at 30-60 DAS and 60-90 DAS)

Net assimilation rate (NAR) (g m^{-2} day^{-1})						
Treatments	**30-60 DAS**			**60-90 DAS**		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	3.19	3.13	3.16	0.87	0.85	0.86
T$_2$	3.35	3.29	3.32	1.21	1.24	1.23
T$_3$	3.29	3.30	3.30	1.08	1.07	1.08
T$_4$	3.35	3.33	3.34	1.38	1.31	1.34
T$_5$	2.93	2.94	2.94	1.26	1.25	1.26
T$_6$	3.23	3.28	3.25	1.28	1.35	1.32
T$_7$	3.39	3.37	3.38	1.44	1.43	1.43
T$_8$	2.81	2.97	2.89	0.78	0.72	0.75
SEm±	0.12	0.09	0.08	0.10	0.09	0.07
CD (P=0.05)	0.36	0.29	0.22	0.31	0.29	0.20

10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) registered a higher NAR (1.34 g m^{-2} day^{-1}) followed by the treatments (T_6, T_3, T_2, T_5 and T_1). During observation, T_8 (unweeded control) indicated a reduction of lower net assimilation rate (0.75 g m^{-2} day^{-1}).

These could result from NAR declining as LAI increases. The net assimilation rate (NAR) increased between 30 and 60 DAS then declined rapidly in 60-90 DAS, and then increased gradually to maturity. During the vegetative phase, the NAR was higher, but during the flowering phase, it decreased. On the other hand, low NAR values could be attributed to limited availability of crucial nutrients, reduced photosynthetic efficiency, or a decreased rate of biomass production as leaves age, and potentially to nutrients deficiency in later stages. This result has close conformity with Bramhankar *et al.* (2018) and Kaziu and Kashta (2018).

4.2.2 Yield attributes:

The perusal of data for the two consecutive years pertaining to the effect of treatments on yield attributes of soybean *viz.* no. of pods per plant, pod length, no. of seeds per pod, pods weight, seed index and 100-seed weight has been presented in Table 4.1.34. During both research seasons, a significant variation was observed in the yield attributes characters due to weed management.

4.2.2.1 Pods per plant:

The number of pods per plant recorded at harvest stage varied significantly as influenced by different weed control treatments and presented in Table 4.1.34 (a). Hand Weeding at 20 and 40 DAS (T_7) recorded a significantly higher number of pods per plant (59.88), followed by T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) recorded 56.62 number of pods per plant in comparison to other treatments and the lowest T_8 (unweeded control) recorded a significantly lower number of pods per plant (43.29) during both seasons of study.

This outcome could be attributed to reduced competition during the critical stages of crop development and improved weed control, which enabled the crop to reach its full potential by absorbing adequate nutrients, light, moisture, and space to facilitate more photosynthetic translocation towards the reproductive parts. Additionally, the presence of favorable agroclimatic conditions created by weed removal may have contributed to the increased number of pods per plant Korav *et al.* (2018). Similar findings were reported by Gupta and Chandrakar (2014), Vimal and Phajage (2014) and Rao (2018).

4.2.2.2 Pods length:

The observation on pod length (Table 4.1.34 a) revealed that hand weeding at 20 and 40 DAS (T_7) recorded the lengthiest pod followed by T4 (Imazethapyr 10 SL @ 100 g a.i. ha-1 (10 DAS) early post emergence – *fb* IC at 30 DAS) which is par with T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) as compared to T_8 (Unweeded control).

4.2.2.3 Number of seed pod^{-1}.

The perusal of data reveals the number of seeds per pods was highest in hand weeding at 20 and 40 DAS (T_7) followed by T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) which is par with T_2 (Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS) as compared to T_8 (un-weeded control). However, all the weed management registered significantly a greater number of seed pods over Unweeded control.

4.2.2.4 Pod weight (g)

Data pertaining to pod weight of soybean for the experimental year is epitomized in Table 4.1.34. It is clear from the finding that among the weed management, hand weeding at 20 and 40 DAS (T_7) recorded significantly higher pod weight (10.89 g) followed by the treatment T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence – *fb* IC at 30 DAS) significantly standing at second place (10.63 g) in the context of pod weight followed by the treatment T_6 (Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS) recorded (10.09 g) pod weight, whereas lesser number of pod weight was observed in T_8 (un-weeded control). All the weed management

Table 4.1.34 (a) Effect of weed management on yield attributes of soybean

	Yield attributes											
Treatments	**Number of pods plant $^{-1}$**			**Pod length (cm)**			**Number of seeds pod $^{-1}$**			**Pod weight (g)**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	46.65	58.92	52.79	3.38	3.49	3.40	2.20	2.23	2.22	8.77	8.95	8.84
T_2	48.70	60.64	54.67	3.65	3.74	3.70	2.40	2.33	2.37	9.93	9.91	9.92
T_3	47.67	59.91	53.77	3.38	3.49	3.41	2.40	2.20	2.30	9.42	9.68	9.55
T_4	50.99	62.26	56.62	3.97	4.08	3.97	2.40	2.47	2.43	10.55	10.72	10.63
T_5	47.95	59.89	53.92	3.53	3.67	3.60	2.30	2.33	2.32	9.56	9.57	9.57
T_6	48.76	61.36	55.08	3.86	3.97	3.88	2.50	2.23	2.37	10.09	10.11	10.09
T_7	55.25	64.52	59.88	3.97	4.08	4.01	2.47	2.50	2.48	10.89	10.89	10.89
T_8	45.28	41.29	43.29	3.27	3.39	3.33	2.13	2.17	2.15	8.07	8.09	8.08
SEm±	*1.81*	*3.17*	*1.82*	*0.14*	*0.15*	*0.10*	*0.07*	*0.07*	*0.05*	*0.31*	*0.30*	*0.22*
CD (P=0.05)	*5.49*	*9.61*	*5.29*	*0.43*	*0.44*	*0.30*	*0.22*	*0.22*	*0.15*	*0.94*	*0.90*	*0.62*

registered significantly a greater number of seed pods over unweeded control. This result has close conformity with Priya *et al*. (2009), Habimana *et al*. (2013).

4.2.2.5 Seed index (g):

The data on number of seed index are depicted in Table 4.1.35. It is generally acknowledged that a crop's grain yield is ultimately determined by environmental factors and agronomic management, with 100-seed weight indicative of a better yield (Deivasigamani and Swaminathan, 2018).

The perusal of data reveal that hand weeding at 20 and 40 DAS (T_7) recorded a significantly highest seed index (9.90 g), followed by T_4 (Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS) recorded second highest (9.70 g) seed index in comparison to other treatments and the lowest seed index (8.49) was recorded at T_8 (unweeded control) during both year of study.

This may be due to weed-free treatment reduced weed competition, which enhanced availability of nutrients and significantly the highest number of seeds per pod and influenced the weed index. This may be due to the application of herbicides showing a promising impact, obtaining a higher test weight than the weedy check. The findings are in corroboration with those of Priya *et al*. (2009), Chandraker and Paikra (2015) and Ahirwar and Ahirwar, (2023).

4.2.2.6 Grain yield (kg ha^{-1})

The perusal of data pertaining to grain yield of soybean are presented in Table 4.1.36 and depicted in Fig. 4.5.

It is quite evident from the pooled data of two season that significantly higher grain yield (2064.67 kg ha^{-1}) was recorded under the hand weeding at 20 and 40 DAS (T_7) during 2019 and 2020 followed by second best treatment Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) which accounted with the grain production of 2005.26 kg ha^{-1} of soybean during investigation. Further glancing of data the Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_2) recorded (1967.36 kg ha^{-1}) the third best treatment and showed its superiority over

Table 4.1.35 Effect of weed management on yield attributes of soybean (seed index & harvest index)

Treatments	**Yield attributes**					
	Seed index (%)			**Harvest index (%)**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	8.71	8.80	8.76	44.18	44.36	44.27
T_2	8.59	9.72	9.16	45.18	45.37	45.27
T_3	8.69	9.17	8.93	44.44	45.07	44.75
T_4	9.68	9.71	9.70	45.07	45.90	45.48
T_5	8.58	9.33	8.95	45.27	44.76	45.02
T_6	9.12	9.39	9.26	45.7	45.09	45.39
T_7	9.80	10.00	9.90	45.62	46.03	45.82
T_8	8.49	8.49	8.49	43.49	44.47	43.98
SEm±	*0.23*	*0.30*	*0.19*	*1.52*	*0.74*	*0.85*
CD (P=0.05)	*0.69*	*0.91*	*0.55*	*NS*	*NS*	*NS*

unweeded control (T_8), which recorded lesser grain yield (997.61 kg ha^{-1}) during course of study. Weeds in unweeded control reduce the seed yield of soybean to the tune of 47.85 and 51.67 per cent during 2019 and 2020, respectively as compared to Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS. This is due to the combined effect of herbicides and interculture. This has a conformity with Kumar *et al*. (2021).

4.2.2.7 Stover yield

The perusal of pooled data during both the seasons of study clearly indicated that the weed management practices had a significant influence on stover yield. The data on stover yield pertaining to weed management are shown in table 4.1.36 and illustrated in Fig. 4.5

It has been observed from the pooled data of two seasons that a significant higher stover yield of soybean was observed under the treatment of hand weeding at 20 and 40 DAS (T_7) with records of 2458.79 kg ha^{-1}, followed by the second-best treatment, Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence – *fb* IC at 30 DAS (T_4), which accounted for the stover production of 2347.13 kg ha^{-1} of soybean during investigation. Further glancing of data, Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_6) recorded (2295.46 kg ha^{-1}) the third best treatment and showed its superiority over unweeded control (T_8), which recorded a lesser stover yield (1312.13 kg ha^{-1}) during the course of investigation. Weeds in unweeded control reduce the stover yield of soybean to the tune of 54.61 and 57.20 percent during 2019 and 2020, respectively, as compared to Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence – *fb* IC at 30 DAS.

4.2.2.8 Biological yield

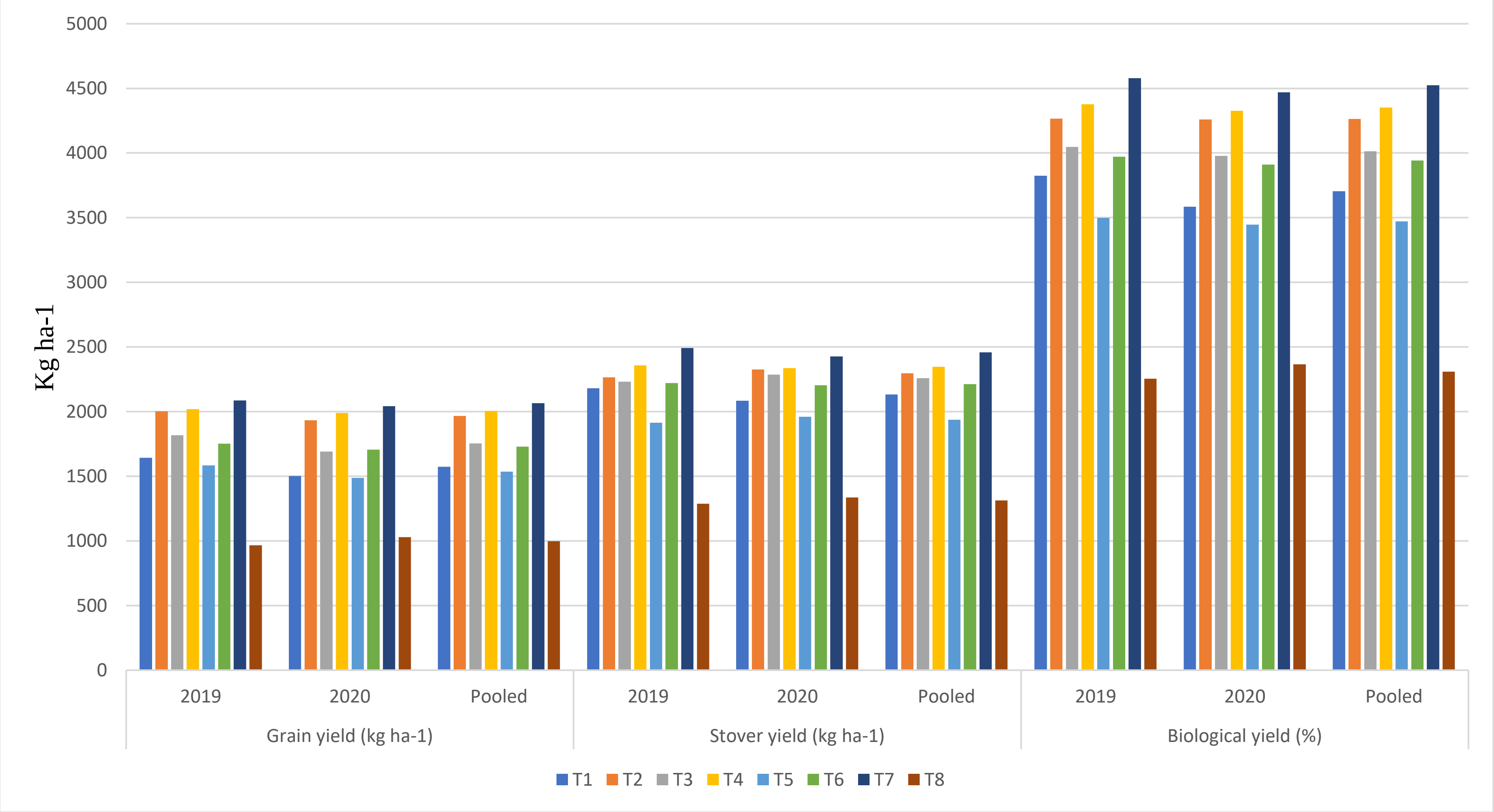
The pooled data of two season on the biological yield (kg ha^{-1}) of soybean are presented in Table 4.1.36 and depicted in Fig. 4.5 and weed management treatments indicate significant variation on the biological yield of soybean.

Among the different weed management practices, it is been observed from the

Table 4.1.36 Effect of weed management on yield attributes of soybean (grain & stover yield and biological yield)

Yield									
Treatments	**Grain yield (kg ha^{-1})**			**Stover yield (kg ha^{-1})**			**Biological yield (%)**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	1486.33	1583.33	1534.83	1960	1914.25	1937.13	3446.33	3497.58	3471.96
T_2	1691.19	1817.03	1754.11	2286.67	2230.92	2258.79	3977.86	4047.95	4012.90
T_3	1501.67	1643.55	1572.61	2083.33	2181.34	2132.34	3585.01	3824.89	3704.95
T_4	1990.51	2020.00	2005.26	2336.67	2357.59	2347.13	4327.18	4377.59	4352.38
T_5	1706.67	1751.62	1729.15	2203.33	2220.92	2212.13	3910	3972.54	3941.27
T_6	1933.22	2001.50	1967.36	2326.67	2264.25	2295.46	4259.88	4265.76	4262.82
T_7	2042.33	2087.00	2064.67	2426.67	2490.92	2458.79	4469	4577.92	4523.46
T_8	1028.67	966.67	997.67	1336.67	1287.59	1312.13	2365.33	2254.25	2309.79
SEm±	*41.78*	*82.21*	*46.11*	*82.29*	*76.16*	*56.06*	*83.41*	*108.66*	*68.49*
CD (P=0.05)	*126.72*	*249.37*	*133.58*	*249.59*	*231.00*	*162.40*	*253.01*	*329.58*	*198.41*

Fig. 4.5 Effect of weed management on yield attributes of soybean (Grain & stover yield and biological yield)



pooled data of two season that significantly higher biological yield of soybean was observed under the treatment hand weeding at 20 and 40 DAS (T_7) with records of 4523.46 kg ha^{-1} followed by second best treatment Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) which accounted the biological yield of 4352.38 kg ha^{-1} of soybean during investigation. A closer look at the data revealed that the Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_6) recorded (4262.82 kg ha^{-1}) the third best treatment and showed its superiority over unweeded control (T_8), which recorded lesser biological yield (2309.79 kg ha^{-1}) during course of investigation. Weeds in unweeded control reduce the stover yield of soybean to the tune of 54.61 and 57.20 per cent during 2019 and 2020, respectively as compared to Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS.

4.2.2.9 Harvest index

The data on the harvest index of soybeans are summarized in Table 4.1.35 and showed that the harvest index was not affected by any weed management treatment applied in the field. Although it is a result of economic and biological yield, weed management practices have little effect on it.

The highest percentage of the harvest index (45.82%) was attributed to the hand weeding treatment at 20 and 40 DAS (T_7). Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post-emergence – *fb* IC at 30 DAS (T_4) was the second best treatment, accounting for 45.48 percent of the harvest index during the field study. Upon detailed examination of the data, it came to light that the Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_6) constituted the third-best treatment with a 45.39 percent harvest index. During the investigation, the unweeded control treatment exhibited the lowest value of the Harvest Index (43.98 %) of all the treatments used.

Grain yield, stover yield, biological yield and harvest index is influenced by both environmental and genotypic factors. It is the most important factor for evaluating the efficacy and superiority of one treatment over another. Weed management methods caused significant variation in soybean seed yield. Weed management at one or more stages, particularly during the critical period of crop-weed competition, led to improved soybean growth and yield characteristics. Favorable crop-growing environments with less disturbance from biotic variables, such as less weed competition, positively impact the productivity of crops. All weed management practices significantly influenced the higher grain yield, stover yield, biological yield and harvest index as compared to weedy check.

Weeds thrive in untreated plots, competing with the crop for nutrients, moisture, space, and sunlight throughout the growing season, eventually inhibiting its growth (Kaur *et al*. 2018). Throughout the seasons of the study, the control that was not weeded produced fewer pods per plant, fewer seeds per pod, and lower test weights. This could be the presence of weeds during the crop period, which hampered pod development and filling, resulting in fewer pods per plant, seeds per pod, and test weight. The test weight plays a crucial role in determining the efficacy and superiority of a particular treatment. The findings are in conformance with Parmar *et al*. (2017), Ahirwar *et al*. (2018) and Meena *et al*. (2022).

The weed management practices created a favorable environment for soybean growth during its critical period resulted in an improvement in grain yield, stover yield, biological yield, and harvest index (Walling *et al*. 2012 and Satyakumari and sagarka 2014). This improvement was attributed to several factors, including the number of branches per plant, pods per plant, seeds per pod, and test weight. In conditions free of weeds, soybean crops can absorb more nutrients from the soil and transfer them to the active site, where these nutrients enhance metabolic processes such as cell division and photosynthesis. This, in turn, leads to the soybean crop producing more yield-related parameters and achieving higher overall yield. Furthermore, these factors may be linked to reduced competition from weeds during the critical stages of crop development. This reduction allows the soybean crop to allocate its resources more efficiently, resulting in higher growth and yield-related attributes compared to the unweeded control, which faced severe weed competition throughout the crop's growth. According to (Deore *et al*. 2009) pre-emergence application of pendimethalin followed by hand weeding and interculture at 30 DAS was found effective for weed control at

Plate 4. Effect of weed management on soybean

Plate 5. Soybean field at maturity

Plate 6. Soybean seed

early stage of soybean crop and post emergence of imazethapyr followed by hand weeding and interculture at 60 DAS was most beneficial to control weeds and increased highest grain and stover yield. These finding corroborate the results reported by Chandraker and Paikra (2015), Jadhav and Kashid (2019) and Charitha *et al*. (2022).

4.3 Herbicide residue (by field bioassay):

Seeds of four test crops, oats, mustard, cucumber, and maize, were planted in Petri dishes in soil obtained from herbicide-treated soybean fields. These crops' seeds were allowed to grow in laboratory conditions under regular observation for eight days. After eight days, all crop plants were uprooted from the Petri dishes, and their plant height and root length were measured as criteria to determine the residual effect of various herbicides applied to soybean crops. The data pertaining to bioassay studies for all the four crops have been appended in Appendices III to Appendices X.

4.3.1 Shoot length

During both years of study, the residue of different herbicides showed no significant influence on the shoot length of all four test crops at any point of observation. However, the shoot lengths of all four crops increased with time, from 30 days to 120 days after weed management.

4.3.2 Root length

Similarly, to the effect on root length, herbicide residue exhibited no significant effect on root length in all four crops during both years of study. Weed management resulted in an increase in root length of 30 to 120 days.

The study revealed that the herbicidal treatments administered in soybeans had no significant effect on the shoot or root lengths of any of the four indicator crops. However, there was an increasing trend for both measures from 30 to 120 days after the herbicide treatment may be attributed to dissipation in the soil with the passage of time. Herbicides applied to soybeans had no detrimental impact on the four crops under investigation, as all herbicidal treatments performed were statistically similar to unweed controls in terms of residual effect.

4.4 Residual effect on succeeding linseed:

The residual problem after herbicide application threatens herbicide usage on a broad scale and restricts the use of herbicides selected for a succeeding crop. In a cropping system, applying herbicides one crop after another causes residue accumulation to build up in the soil and on the crop, which can negatively impact subsequent crops. Assessing herbicide residue and persistence in the soil must be evaluated applied weed management in a way that is non-hazardous, safe, and effective. The bioassay is a crucial technique for estimating the quantity of herbicide residue in soil, both qualitatively and quantitatively.

Data pertaining to yield attributes on plant population, plant height (cm), dry matter (g) and seed yield (kg ha^{-1}) of lensed as affected by weed management in soybean have been described in this section.

4.4.1 Plant population (no. m^{-2})

In residual effect, the results revealed that the plant population of linseed showed that there was a significant difference among treatments at 30 DAS in 2019 and 2020. The data is presented in Table 4.1.37.

The data revealed that linseed plant population 30 DAS, application of Sulfentrazone 48 SC @ 360 g a.i. ha^{-1}-post emergence, 20 DAS (T_5) significantly lower plant population (63.35) and it was on par with Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} (10 DAS) early post emergence *fb* IC at 30 DAS, 20 DAS (T_6) recorded (67.30) during the seasons of study. The highest plant population (81.27) was observed at IC at 20 DAS *fb* Hand weeding at 40 DAS and it was on par with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} - Post emergence – *fb* IC at 30 DAS (T_4).The results are also in close conformity with the finding of Sondia and Gopal (2009) stated that 72 per cent herbicides showed faster dissipation by various means and only 9.3 percent herbicides are responsible below the maximum limit which showed adverse effect or toxicity to soil or succeeding crop. This was in accordance with the findings of Janaki *et al*. (2012), Deore and Patil (2016) and Rani *et al*. (2022).

4.4.2 Plant height (cm)

The plant height was recorded at 30 DAS and presented in Table 4.1.37.

Weed management of soybean failed to exert significant difference of the plant height of linseed at 30 DAS during 2019 and 2020.

4.4.3 Dry matter production (g)

The dry matter production of residual crops was recorded at 30 DAS and presented in Table. 4.1.37 and Fig. 4.6.

In weed management at 30 DAS, there was a significant difference among treatments. The highest dry matter (1.10 g plant^{-1}) was found at IC at 20 DAS *fb* hand weeding at 40 DAS (T_7) and was at par with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) followed by the treatment of Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_6). Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} - Pre emergence (T_1) observed lowest dry matter (0.87 g plant^{-1}) and they were at par with Sulfentrazone 48 SC @ 360 g a.i. ha^{-1}-post emergence, 20 DAS (T_5), Imazethapyr 10 SL @ 100 g a.i. ha^{-1} - Post emergence, 20 DAS (T_3). This trend was confirmed by Zahana *et al.* (2018).

4.4.4 Seed yield (kg ha^{-1})

The seed yield of linseed as residual crops was recorded and there was a significant difference among treatments which is presented in Table 4.1.37 and Figure 4.6.

In weed management at 30 DAS, there was a significant difference among treatments. The highest seed yield (710.75 kg ha^{-1}) was found at IC at 20 DAS *fb* hand weeding at 40 DAS (T_7) and was at par with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10

Table 4.1.37 Effect of weed management on plant population, plant height, dry matter and yield of Linseed

Yield attributes												
Treatments	***Plant population (m^{-2})***			***Plant height (cm)***			***Dry matter (g)***			***Seed yield (kg ha^{-1})***		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	78.45	80.65	79.55	7.81	7.37	7.59	0.85	0.89	0.87	577.98	571.71	574.84
T_2	81.32	78.80	80.06	7.53	8.61	8.07	0.94	0.95	0.94	613.51	591.01	602.26
T_3	73.92	69.40	71.66	7.67	7.85	7.76	0.83	0.87	0.85	573.58	584.84	579.21
T_4	78.95	82.39	80.67	8.17	8.73	8.45	1.06	1.08	1.07	642.96	675.19	659.08
T_5	63.35	63.35	63.35	7.94	7.91	7.93	0.91	0.91	0.91	589.49	597.11	593.30
T_6	66.30	68.30	67.30	8.11	8.13	8.12	1.00	0.99	1.00	626.40	616.71	621.56
T_7	80.88	81.66	81.27	8.41	8.71	8.56	1.10	1.11	1.10	715.99	705.51	710.75
T_8	59.22	56.01	57.62	7.31	7.12	7.22	0.77	0.84	0.80	485.83	534.46	510.14
SEm±	*4.11*	*4.61*	*3.09*	*0.54*	*0.46*	*0.36*	*0.03*	*0.03*	*0.02*	*31.34*	*26.40*	*20.49*
CD (P=0.05)	*12.46*	*13.99*	*8.94*	*NS*	*NS*	*NS*	*0.09*	*0.08*	*0.06*	*95.07*	*80.06*	*59.35*

Fig 4.6 Effect of weed management on dry matter and yield of Linseed

DAS) early post emergence – *fb* IC at 30 DAS (T_4) followed by (659.08 kg ha^{-1}). Further glancing of data the Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_2) recorded (621.56 kg ha^{-1}) the third best treatment and showed its superiority over un-weeded control (T_8), which recorded lesser grain yield (510.14 kg ha^{-1}) during course of study. Similar finding was reported by Sondhia and Gopal (2009), Yadav and Bhullar (2014) and Rani *et al.* (2022)

Overall, the study found that the residual toxicity of the herbicides had a significant impact on the growth and yield of the linseed crops. The plant population was lower, plant height was reduced, and dry matter accumulation was also affected. However, despite these negative effects, there was still a noticeable seed yield, indicating that the herbicides did not completely inhibit crop growth. This information will be crucial for farmers to consider when choosing which herbicides to use in their fields, balancing the need for effective weed control with the potential risks to their crops and the environment. By understanding the long-term effects of herbicide use, farmers can make more sustainable and environmentally conscious decisions for their farming practices.

4.4.5 Economic analysis of succeeding crop

The data on linseed of soybean indicating cost of cultivation, gross return, net return, and benefit: cost ratio (BCR) under different weed management was estimated and documented for both cropping seasons, and the data are provided in Table 4.1.38 along with the illustrated graphically in Fig. 4.7 and 4.8. The details of economics are also furnished in Appendix-I.

4.4.5.1 Cost of cultivation

Appraisal of data showed that cost of cultivation (₹ 13,300 ha^{-1}) was incurred for all the weed management of linseed cultivation. This cost included seed, planting, harvesting, threshing, drying, and winnowing.

4.4.5.2 Gross return

The data revealed that maximum gross returns (₹ 49,753 ha^{-1}) was obtained with IC at 20 DAS *fb* hand weeding at 40 DAS (T_7), followed by Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4), Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} (10 DAS) early post emergence *fb* IC at 30 DAS, 20 DAS (T_6). However, minimum gross returns (₹ 35,710 ha^{-1}) were achieved with the unweeded control (T_8). Higher gross returns might be attributed to higher grain and straw yield associated with weed management. The results confirmed to reports of Venkatesh *et al*. (2008), Ahirwar *et al*. (2018) and Binjha *et al*. (2022).

4.4.5.3 Net returns

A glance of the data indicates that maximum net realization of (₹ 36,453 ha^{-1}) was obtained with the application of IC at 20 DAS *fb* and weeding at 40 DAS (T_7), which was closely followed by Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) and Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} (10 DAS) early post emergence *fb* IC at 30 DAS, 20 DAS (T_6). Whereas, the lower net realization (₹ 22,410 ha^{-1}) was obtained with Unweeded control (T_8).

4.4.5.4 Benefit: Cost ratio (B:C)

Among different weed management treatments, the higher B:C ratio (2.71) was obtained with IC at 20 DAS *fb* hand weeding at 40 DAS (T_7) which was comparable followed Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4). The unweeded control (T_8) recorded the lower B:C ratio (1.68). Similar finding was also reported by Nagre *et al*. (2017), Rajkumari *et al*. (2017) and Ahirwar and Ahirwar (2023)

4.5 Soil microbial analysis

4.5.1 Soil bacteria (cfu g^{-1})

Table 4.1.39 depicts the number of soil bacteria (cfu g^{-1}) recorded during crop harvest in 2019 and 2020. It can be observed that weed management had no substantial effect on soil microorganisms in both years.

Table 4.1.38 Effect of weed management combination on economics of linseed cultivation

Treatments	Cost of cultivation (ha^{-1})	Gross returns (₹ ha^{-1})			Net returns (₹ ha^{-1})			Benefit cost ratio		
		2019	2020	Average	2019	2020	Average	2019	2020	Average
T$_1$	13300.00	40459	40020	40239	27459	27020	27239	2.11	2.08	2.10
T$_2$	13300.00	42946	41371	42158	29646	28071	28858	2.23	2.11	2.17
T$_3$	13300.00	40151	40939	40545	26851	27639	27245	2.02	2.08	2.05
T$_4$	13300.00	45007	47263	46135	31707	33963	32835	2.38	2.55	2.47
T$_5$	13300.00	41264	41798	41531	27964	28498	28231	2.10	2.14	2.12
T$_6$	13300.00	43848	43170	43509	30548	29870	30209	2.30	2.25	2.27
T$_7$	13300.00	50119	49386	49753	36819	36086	36453	2.77	2.71	2.74
T$_8$	13300.00	34008	37412	35710	20708	24112	22410	1.56	1.81	1.68

Fig. 4.7 Effect of weed management combination on Gross returns (₹ ha^{-1}) and Net returns (₹ ha^{-1}) of linseed cultivation

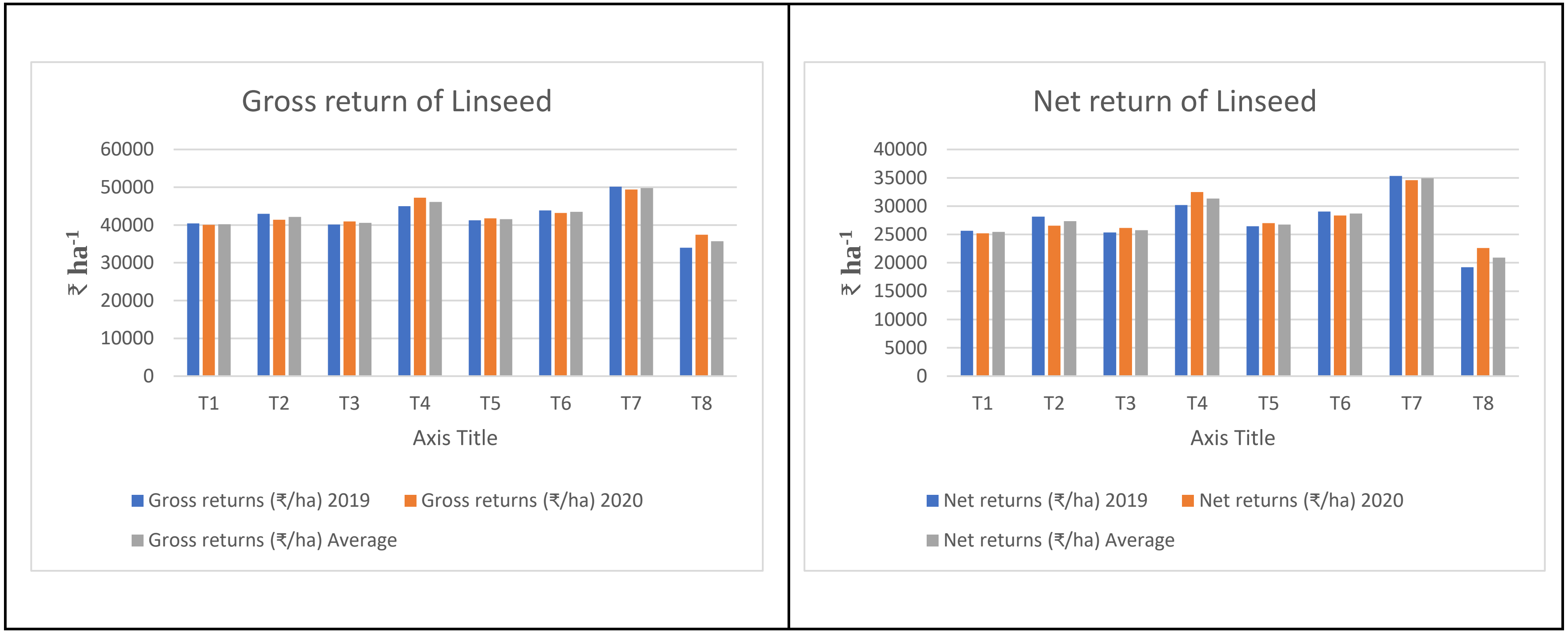


Fig. 4.8 Effect of weed management combination on benefit cost ration (B:C) of succeeding Linseed

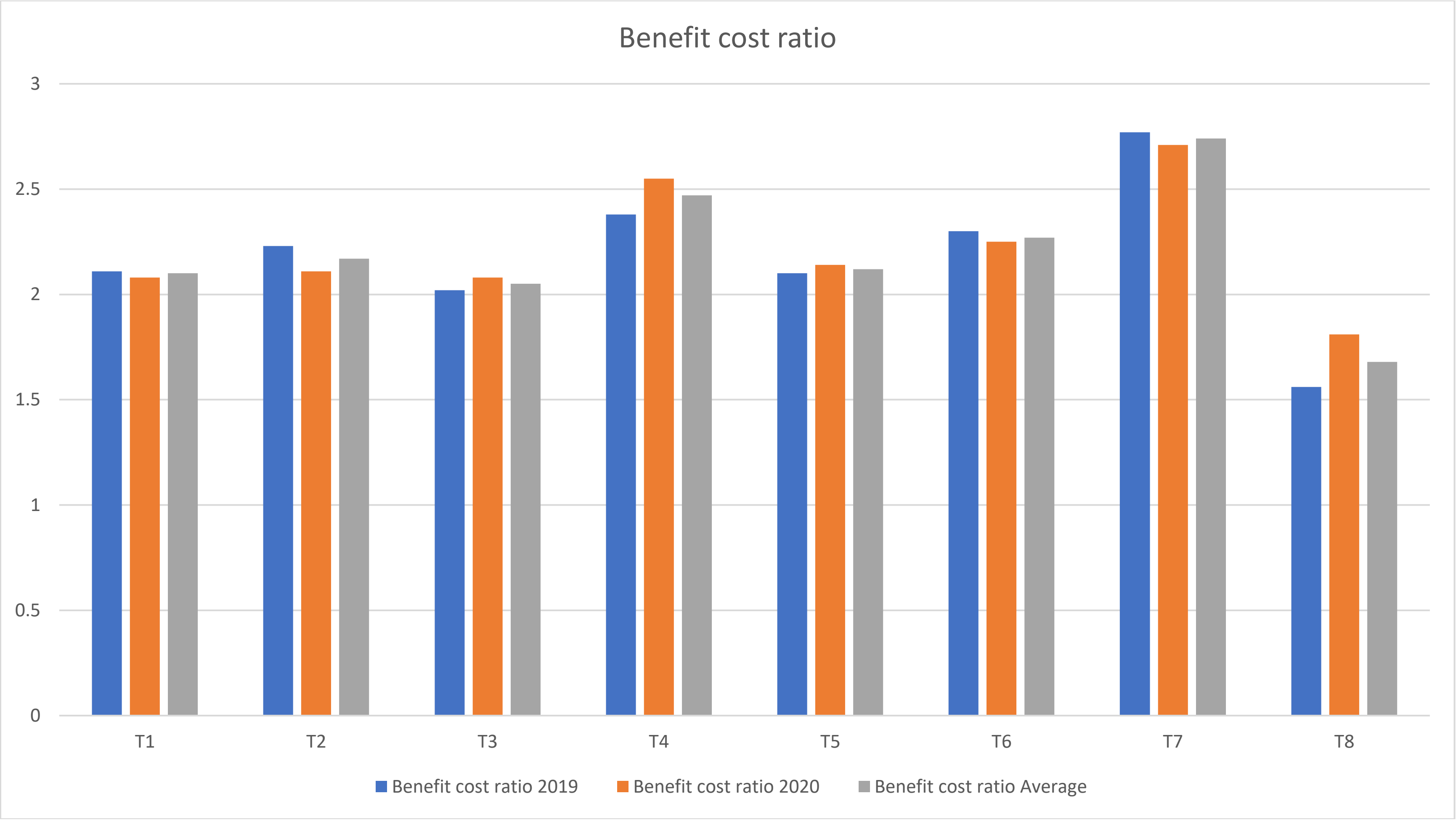


Plate 7. Field of succeeding Linseed

Table 4.1. 39 Effect of weed management on Soil microbial count (CFU g^{-1})

Soil microbial count (CFU g^{-1})												
Treatments	**Bacteria**			**Actinomycetes**			**Fungi**			**Total microbial count**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	32.08	34.58	33.33	1.69	1.56	1.62	37.34	39.23	38.28	71.11	75.37	73.24
T_2	33.79	35.86	34.83	1.70	1.50	1.60	37.52	35.55	36.53	71.72	71.80	71.76
T_3	32.88	35.49	34.19	1.71	1.52	1.62	37.50	34.04	35.77	72.09	71.05	71.57
T_4	33.93	35.95	34.94	1.78	1.60	1.69	37.63	33.67	35.65	73.12	73.56	73.34
T_5	32.50	34.74	33.62	1.73	1.53	1.63	37.60	36.17	36.88	73.34	71.22	72.28
T_6	31.49	34.11	32.80	1.63	1.48	1.55	35.66	35.67	35.66	68.78	71.25	70.02
T_7	34.04	35.22	34.63	1.78	1.61	1.69	37.89	35.35	36.62	73.79	73.64	73.72
T_8	35.31	35.69	35.50	1.80	1.63	1.71	37.96	36.80	37.38	74.98	72.65	73.81
SEm±	*1.29*	*1.36*	*0.94*	*0.06*	*0.06*	*0.04*	1.36	1.45	0.99	1.72	1.92	1.29
CD (P=0.05)	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

4.5.2 Soil fungi (cfu g^{-1})

In Tables 4.1.39 show that weed management had no apparent effect on soil fungus in either year.

4.5.3 Soil actinomycetes (cfu g^{-1})

Weed management had no significant influence on soil actinomycetes in both years, which is presented in Tables 4.1.39.

4.6 Soil analysis

4.6.1 pH (Soil reaction)

Effects of weed management on pH were found to be non-significant in both the years and are presented in Table 4.1.40.

4.6.2 Organic carbon (%)

Data pertaining to organic carbon as influenced by weed management presented in Table 4.1.40. Organic carbon was found to be non-significant in both the years.

4.6.3 Electrical conductivity (d Sm^{-1})

Data pertaining to electrical conductivity (dSm^{-1}) as influenced by weed management presented in Table 4.1.40 Electrical conductivity found to be non-significant in both the years.

4.6.4 Available Nitrogen (kg ha^{-1}) status after harvest

The perusal of data pertaining available nitrogen (kg ha^{-1}) status after harvested is presented in Table. 4.1.41 which had a significantly affected in both the years by weed management.

An analysis of the pooled data clearly revealed that significantly higher available nitrogen (311.87 kg ha^{-1}) was recorded in IC at 20 DAS *fb* Hand weeding at

Table 4.1.40 Effect of weed management on soil nutrients status after harvest

Soil nutrient status after harvest (kg ha $^{-1}$)									
Treatments	**Soil pH**			**Electrical conductivity (d Sm^{-1})**			**Organic carbon (%)**		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	4.54	4.59	4.56	0.21	0.24	0.22	1.53	1.58	1.55
T_2	4.50	4.56	4.53	0.20	0.23	0.21	1.50	1.55	1.53
T_3	4.49	4.50	4.49	0.18	0.21	0.19	1.49	1.51	1.50
T_4	4.58	4.67	4.63	0.24	0.27	0.25	1.57	1.63	1.60
T_5	4.52	4.59	4.55	0.22	0.24	0.23	1.53	1.58	1.55
T_6	4.58	4.62	4.60	0.23	0.25	0.24	1.55	1.60	1.57
T_7	4.66	4.71	4.69	0.27	0.28	0.27	1.60	1.65	1.63
T_8	4.42	4.47	4.44	0.16	0.19	0.17	1.44	1.50	1.47
SEm±	*0.15*	*0.15*	*0.11*	*0.03*	*0.02*	*0.02*	*0.06*	*0.06*	*0.04*
CD (P=0.05)	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

Table 4.1.41 Effect of weed management on soil available nutrients status after harvest

Soil available nutrients status after harvest (kg ha^{-1})									
Treatments	**Available nitrogen (kg ha^{-1})**			**Available phosphorus (kg ha^{-1})**			**Available potassium (kg ha^{-1})**		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T$_1$	253.08	264.85	258.97	16.76	15.57	16.17	139.86	149.53	144.69
T$_2$	258.12	271.39	264.76	17.12	16.77	16.94	143.96	155.55	149.75
T$_3$	257.18	269.78	263.48	17.07	16.75	16.91	143.25	154.93	149.09
T$_4$	260.90	276.00	268.45	17.61	16.87	17.24	143.99	156.33	150.16
T$_5$	250.04	258.80	254.42	16.57	14.58	15.58	138.86	148.27	143.56
T$_6$	254.68	269.12	261.90	16.77	16.71	16.74	142.78	151.55	147.16
T$_7$	299.39	324.34	311.87	17.63	16.93	17.28	144.32	159.99	152.15
T$_8$	239.09	248.67	243.88	13.84	11.31	12.57	135.95	139.15	137.55
SEm±	*10.04*	*11.72*	*7.72*	*0.71*	*1.07*	*0.64*	*7.63*	*8.17*	*5.59*
CD (P=0.05)	*30.47*	*35.55*	*22.36*	*2.16*	*3.24*	*1.86*	*NS*	*NS*	*NS*

40 DAS (T_7). It was further comparable with treatment Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) recorded second highest available nitrogen (268.45 kg ha^{-1}). The lowest (243.88 kg ha^{-1}) available nitrogen status after harvested was registered on Unweeded control (T_8).

4.6.5 Available phosphorus (kg ha^{-1}) status after harvest

The perusal of data pertaining available phosphorus (kg ha^{-1}) status after harvested is presented in Table. 4.1.41 was significantly affected in both the years by weed management.

Available phosphorus (17.28 kg ha^{-1}) was recorded higher in IC at 20 DAS *fb* hand weeding at 40 DAS (T_7). It was further comparable with treatment Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) recorded second highest available nitrogen (268.45 kg ha^{-1}) after harvest. Unweeded control (T_8) registered lowest (12.57 kg ha^{-1}) available phosphorus status after harvested in both the years and pooled results.

4.6.6 Available potassium (kg ha^{-1}) status after harvest

Data pertaining to available phosphorus (kg ha^{-1}) status after harvest found to be non-significant in both the years and pooled results are presented in Table 4.1.41.

The concentration or availability of N, P and K observed under weed management might be attributed to the reduction in crop weed competition, which enhances and improves nutrient availability, better growth, and higher dry matter production. These results are in close conformity with Dhayal *et al.* (2022) and Vishwakarma *et al.* (2023).

4.7 Plant analysis

4.7.1 NPK uptake by weeds (kg ha^{-1})

4.7.1.1 Effect of nitrogen uptake by weeds (kg ha^{-1})

The data pertaining on nitrogen uptake by weeds at harvest as influenced due to different weed management treatment are presented in Table 4.1.42. The data are also graphically depicted in Fig. 4.9.

Weed management treatment significantly affected nitrogen uptake on weed over both years, as revealed by the pooled data.

Significantly, the lowest N uptake by weeds was recorded (3.93 kg ha^{-1}) under IC at 20 DAS *fb* Hand weeding at 40 DAS (T_7) over all other treatments in 2019 and 2020 as well as in pooled results. Subsequently, the next best treatment was observed in N uptake by weeds (6.25 kg ha^{-1}) on Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4). Significantly, the highest N uptake was 43.45, 35.68 and 39.57 kg ha^{-1} by weeds during 2019 and 2020, and in polled results, respectively, was recorded with unweeded control (T_8).

4.7.1.2 Effect of phosphorus uptake by weeds

The results pertaining to phosphorus uptake by weeds at harvest as influenced due to different weed management treatment are presented in Table 4.1.42 and graphically depicted in Fig 4.9.

Weed management treatment influenced significantly affected weed uptake on phosphorus over both years, as revealed by the pooled data.

Significantly, the lowest P uptake by weeds was recorded (2.71 kg ha^{-1}) under IC at 20 DAS *fb* Hand weeding at 40 DAS (T_7) over all other treatments in 2019 and 2020 as well as in pooled results, and it was followed by Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) and Sulfentrazone 48 SC @360 g ha^{-1} at 20 DAS *fb* IC at 30 DAS in pooled results. The maximum uptake of phosphorus 35.79, 31.12 and 33.46 kg ha^{-1} by weeds occurred under unweeded control (T_8) during 2019 and 2020, and in pooled results, respectively. Unweeded control recorded significantly higher values of phosphorus removal by weeds at all stages of observation.

4.7.1.3 Effect of potassium uptake by weeds (kg ha^{-1})

The data on potassium uptake by weeds as influenced due to different weed control treatments are presented in Table 4.1.42. The data are also graphically depicted in Fig. 4.9.

Different weed management treatments recorded significantly lower depletion of potassium by weeds as compared to unweeded control during 2019 and 2020 and in pooled results. Significantly the lowest K uptake by weeds (1.44 kg ha^{-1}) was recorded under IC at 20 DAS *fb* hand weeding at 40 DAS (T_7) in both the years as well as in the pooled results. However, statistically it remained at par with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) and with remaining treatments (T_4, T_2, T_6 and T_3) except Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} - Pre emergence (T_1) in the pooled results. The maximum loss of potassium 21.07, 18.21 and 19.64 kg ha^{-1} by weeds was occurred under unweeded control (T_8) in both pooled, respectively.

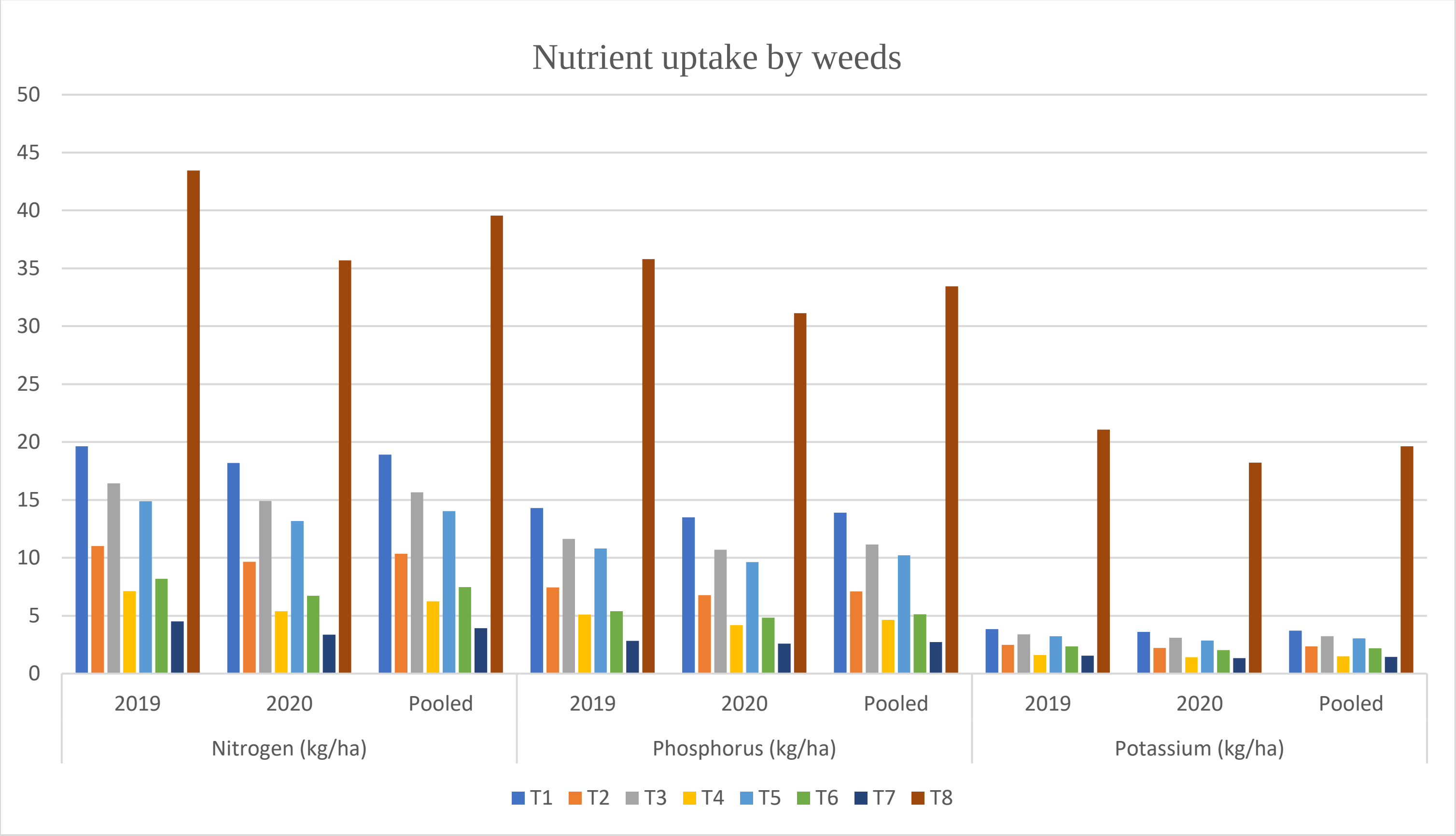
Nitrogen, phosphorus and potassium (Tables 4.1.42) uptake by weeds was significantly higher under unweeded control (T_8). As in weed, uptake of nutrients was significantly lower in weed-free treatment. This is due to no control of weeds, which allows the weeds to harness nutrients to their full potential. Similar finding has been reported by Dhayal *et al.* (2022) and Borje *et al.* (2023).

Among different treatments, the minimum loss of nutrients by weeds was under Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) followed by the treatment pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS (T_2). These treatments were also found equivalent to weed free. Singh *et al.* (2017) reported that nutrient uptake is a numerical product of nutrient content and dry matter accumulation. Higher nutrient uptake might be due to less or no contribution of weeds in soybean nutrient removal. This was due to minimum nutrient uptake by weeds ultimately decrease dry matter production of weeds. The results could be supported by studies of Sharma *et al.* (2016), Bhimwal *et al.* (2018) and Horvath *et al.* (2023).

Table 4.1.42 Effect of weed management on nutrient uptake by weeds (kg ha^{-1}) at harvest

Nutrient uptake by weeds (kg ha^{-1}) at harvest									
Treatments	**Nitrogen (kg ha^{-1})**			**Phosphorus (kg ha^{-1})**			**Potassium (kg ha^{-1})**		
	2019	***2020***	***Pooled***	***2019***	***2020***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	19.64	18.18	18.91	14.30	13.50	13.90	3.84	3.60	3.72
T_2	11.01	9.67	10.34	7.44	6.77	7.10	2.49	2.22	2.36
T_3	16.42	14.90	15.66	11.63	10.69	11.16	3.38	3.10	3.24
T_4	7.13	5.38	6.25	5.10	4.20	4.65	1.60	1.41	1.50
T_5	14.88	13.17	14.03	10.80	9.64	10.22	3.22	2.86	3.04
T_6	8.20	6.73	7.47	5.38	4.84	5.11	2.36	2.03	2.19
T_7	4.52	3.35	3.93	2.83	2.59	2.71	1.55	1.34	1.44
T_8	43.45	35.68	39.57	35.79	31.12	33.46	21.07	18.21	19.64
SEm±	*1.04*	*1.12*	*0.76*	*1.35*	*0.82*	*0.79*	*0.12*	*0.59*	*0.30*
CD (P=0.05)	*3.15*	*3.40*	*2.21*	*4.09*	*2.48*	*2.28*	*0.36*	*1.77*	*0.86*

Fig. 4.9 Effect of weed management on nutrient uptake by weeds (kg ha^{-1}) at harvest



4.7.2 Nutrient uptake by crop

4.7.2.1 Effect of nitrogen uptake in crop (grain + stover)

The data pertaining to nitrogen uptake by crop (grain + stover) at harvest as influenced due to different weed management treatment are presented in Table 4.1.43. Weed management treatment significantly affected nitrogen uptake on crop (grain + stover) over both years, as revealed by the pooled data.

Significantly, the highest N uptake by crop (grain + stover) was recorded (136.67 and 53.91 kg ha^{-1}) under IC at 20 DAS *fb* hand weeding at 40 DAS (T_7) over all other treatments in 2019 and 2020 as well as pooled results. Following that, the next best treatment (130.42 and 48.45 kg ha^{-1}) was observed in N uptake by crop (grain + stover) on Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) and in Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_6) observed (119.96 and 43.39 kg ha^{-1}) third best N uptake by crop (grain + stover)**.** Furthermore, the least N uptake was 53.35 and 17.72 kg ha^{-1} was recorded by crop (grain + stover) during 2019 and 2020, and polled results, respectively, was recorded with unweeded control (T_8).

4.7.2.2 Effect of phosphorus uptake in crop (grain + stover)

The results pertaining to phosphorus uptake by crop (grain + stover) at harvest as influenced due to different weed management treatments are presented in Table 4.1.44.

Weed management treatment influenced significantly affected crop (grain + stover) uptake on phosphorus over both years, as revealed by the pooled data.

Significantly, the highest P uptake by crop (grain + stover) was recorded (6.67 and 6.62 kg ha^{-1}) under IC at 20 DAS *fb* hand weeding at 40 DAS (T_7) over all other treatments in 2019 and 2020 as well as in pooled results, however, it was statistically at par with (6.20 and 6.07 kg ha^{-1}) Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) and (5.94 and 5.30 kg ha^{-1}) Sulfentrazone 48 SC @360 g a.i. ha^{-1} I IC at 30 DAS (T_6) in pooled results. The minimum uptake of

Table 4.1.43 Effect of weed management on nitrogen uptake by crop [grain and stover (kg ha^{-1})] at harvest

Treatments	**Nitrogen uptake by crop at harvest**					
	Grain (kg ha^{-1})			**Stover (kg ha^{-1})**		
	2019	***2019***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	83.60	86.56	85.08	28.43	29.82	29.12
T_2	101.90	109.45	105.67	39.59	41.87	40.73
T_3	86.98	90.28	88.63	35.97	31.87	33.92
T_4	124.95	135.90	130.42	47.22	49.67	48.45
T_5	99.87	100.94	100.40	39.04	38.40	38.72
T_6	117.40	122.52	119.96	41.65	45.12	43.39
T_7	128.84	144.50	136.67	51.54	56.27	53.91
T_8	56.50	50.20	53.35	17.77	17.66	17.72
SEm±	*3.02*	*3.16*	*2.18*	*1.81*	*2.03*	*1.36*
CD (P=0.05)	*9.15*	*9.58*	*6.32*	*5.48*	*6.17*	*3.94*

Table 4.1.44 Effect of weed management on phosphorus uptake by crop [grain and stover (kg ha^{-1})] at harvest

Treatments	**Phosphorus uptake by crop at harvest**					
	Grain (kg ha^{-1})			**Stover (kg ha^{-1})**		
	2019	***2019***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	4.18	3.95	4.07	2.83	3.22	3.02
T_2	4.94	5.30	5.12	4.87	5.35	5.11
T_3	4.36	4.30	4.33	3.80	3.75	3.78
T_4	5.61	6.79	6.20	6.08	6.07	6.07
T_5	4.80	5.31	5.06	3.94	4.34	4.14
T_6	5.63	6.25	5.94	5.26	5.33	5.30
T_7	6.16	7.18	6.67	6.67	6.56	6.62
T_8	2.20	2.45	2.33	1.78	2.04	1.91
SEm±	*0.34*	*0.25*	*0.21*	*0.31*	*0.33*	*0.23*
CD (P=0.05)	*1.03*	*0.74*	*0.61*	*0.94*	*0.99*	*0.65*

Table 4.1.45 Effect of weed management on potassium uptake by crop [grain and stover (kg ha^{-1})] at harvest

Treatments	**Potassium uptake by crop at harvest**					
	Grain (kg ha^{-1})			**Stover (kg ha^{-1})**		
	2019	***2019***	***Pooled***	***2019***	***2020***	***Pooled***
T_1	22.47	21.74	22.10	38.81	41.29	40.05
T_2	27.19	25.66	26.42	46.81	46.07	46.44
T_3	25.74	25.22	25.48	45.70	39.86	42.78
T_4	33.07	31.49	32.28	50.40	52.77	51.58
T_5	23.86	22.16	23.01	44.81	42.04	43.42
T_6	30.43	29.75	30.09	47.83	48.98	48.40
T_7	35.05	32.99	34.02	53.50	57.78	55.64
T_8	12.49	14.03	13.26	23.03	22.88	22.95
SEm±	*1.46*	*0.74*	*0.82*	*1.55*	*2.49*	*1.47*
CD (P=0.05)	*4.43*	*2.26*	*2.37*	*4.70*	*7.57*	*4.25*

phosphorus by crop (grain + stover) recorded 2.33 and 1.91 kg ha^{-1} occurred under unweeded control (T_8) during 2019 and 2020, and in pooled results, respectively.

4.7.2.3 Effect of potassium uptake in crop (grain + stover)

The data on potassium uptake by crop (grain + stover) as influenced due to different weed control treatments are presented in Table 4.1.45.

Different weed management treatments recorded significantly highest potassium uptake of by crop (grain + stover) compared to unweeded control during 2019 and 2020 and as well as in pooled results. Significantly the highest K uptake by crop (grain + stover) (34.02 and 55.64 kg ha^{-1}) was recorded under IC at 20 DAS *fb* hand weeding at 40 DAS (T_7) in both the years as well as in the pooled results. Following that, the next best uptake of K (32.28 and 51.58 kg ha^{-1}) was observed Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) and it remained statistically at par with Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_6). The maximum loss of potassium uptake of 13.26 and 22.95 kg ha^{-1} by crop (grain + stover) was occurred under unweeded control (T_8) during 2019 and 2010, and in pooled results, respectively.

It was observed that uptake of nutrients was significantly higher in unweeded treatment. Monteiro and Santos (2022) revealed that unweeded, weeds hinder the growth of crops by competing for resource utilization for essential resources, resulting in significant losses in crop production. The maximum uptake of NPK was observed under Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) followed by the treatment Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_6). This might be attributable to the early and effective weed control achieved with a combination of pre and post emergence herbicides, followed by the cultural method, which reflected in a lower number of weeds, which ultimately decreased weed density and dry matter accumulation by weeds and, as a result, lower weed uptake of nutrients while increasing soybean uptake. This result is in conformity with Kumar *et al*. (2022b) and Vishwakarma *et al*. (2023).

4.8 Economics analysis:

The data on economics of soybean indicating cost of cultivation, gross return, net return, and benefit: cost ratio (BCR) under different weed management is presented in Table 4.1.46. The data also illustrated graphically in Fig. 4.10 and 4.11. The details of economics are also furnished in Appendix-I (a) and II.

4.8.1 Cost of cultivation

The cost of cultivation for soybean was estimated and documented for both cropping seasons, and the results are provided in Table 4.1.46.

Appraisal of data showed the highest cost of cultivation (₹ 51,491 ha^{-1}) was incurred with the IC at 20 DAS *fb* hand weeding at 40 DAS (T_7), which was followed by Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS (T_2). and Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS (T_6) and on the other hand, lower cultivation cost (₹ 44,891 ha^{-1}) was obtained with unweeded control (T_8).

4.8.2 Gross returns

The data revealed that maximum gross returns (₹ 18,36,00 ha^{-1}) was obtained with IC at 20 DAS *fb* Hand weeding at 40 DAS (T_7), followed by Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4), Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} (10 DAS) early post emergence *fb* IC at 30 DAS, 20 DAS (T_6), Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS (T_2). However, minimum gross returns (₹ 81,150 ha^{-1}) were achieved with the unweeded control (T_8). This might be an increase in income obtained with weed management treatments, which could have been attributable to effective weed control efficiency, which would have increased soybean seed production while reducing weed control investment expenditures. These results are in close conformity with the findings of Meena and Dhaka (2013), Habimana *et al.* (2014), Ahirwar *et al.* (2018), Rao *et al.* (2018) and Kumar *et al.* (2022b).

Table 4.1.46 Effect of weed management combination on economics of soybean cultivation

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})			Net returns (₹ ha^{-1})			Benefit cost ratio		
		2019	2020	Average	2019	2020	Average	2019	2020	Average
T_1	47181	136866	144750	140808	89686	97569	93627	1.90	2.07	1.98
T_2	49281	153582	163689	158635	104301	114408	109355	2.12	2.32	2.21
T_3	46841	138217	149771	143994	91376	102930	97153	1.95	2.20	2.07
T_4	48941	177577	179937	178757	128637	130996	129816	2.63	2.68	2.65
T_5	46942	154737	158090	156413	107795	111148	109471	2.30	2.37	2.33
T_6	49042	172984	178323	175654	123942	129281	126612	2.53	2.64	2.58
T_7	51491	181813	185387	183600	130322	133896	132109	2.53	2.60	2.56
T_8	44891	78670	83630	81150	33779	38739	36259	0.75	0.86	0.80

Fig. 4. 10 Effect of weed management combination on economics of soybean cultivation

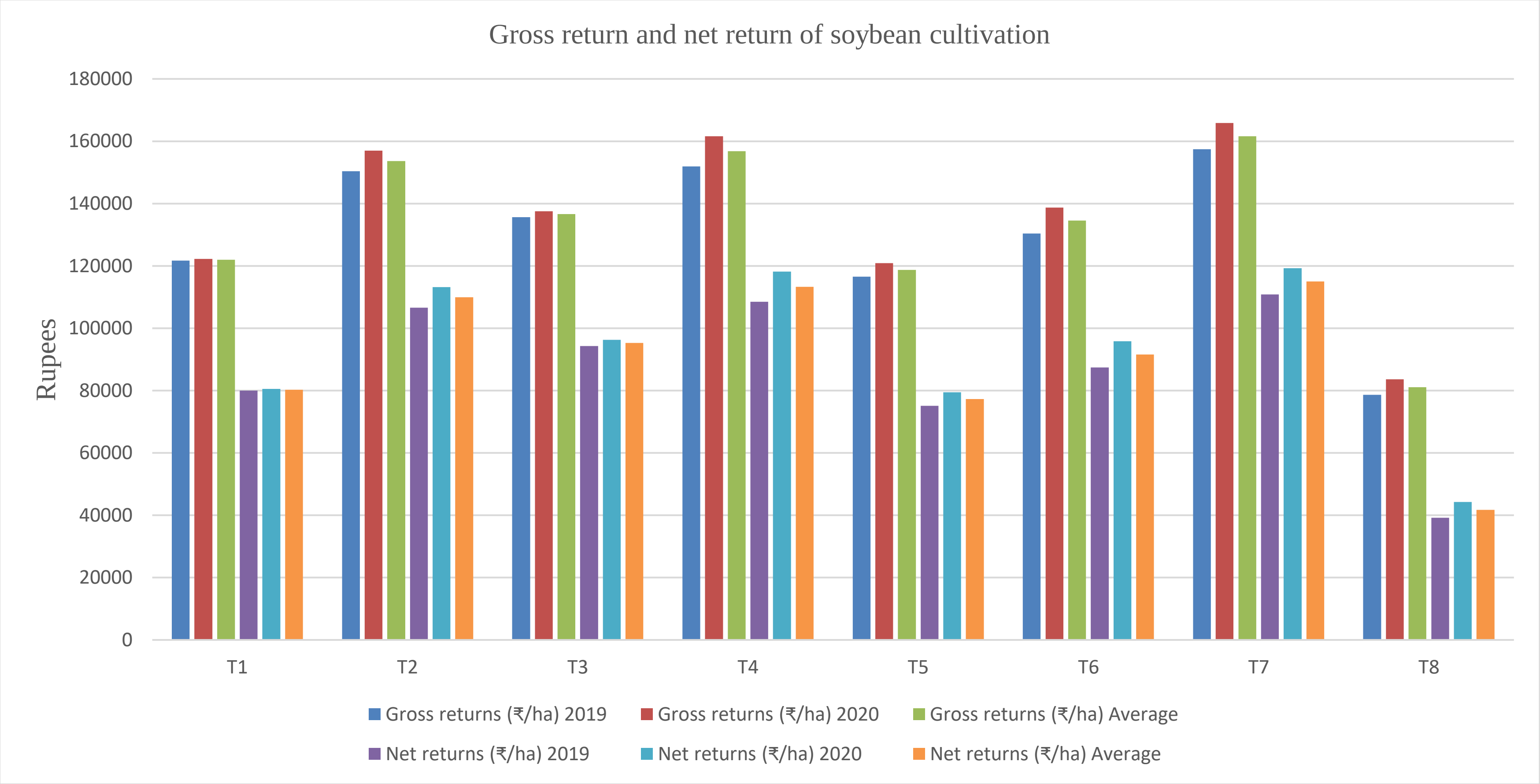
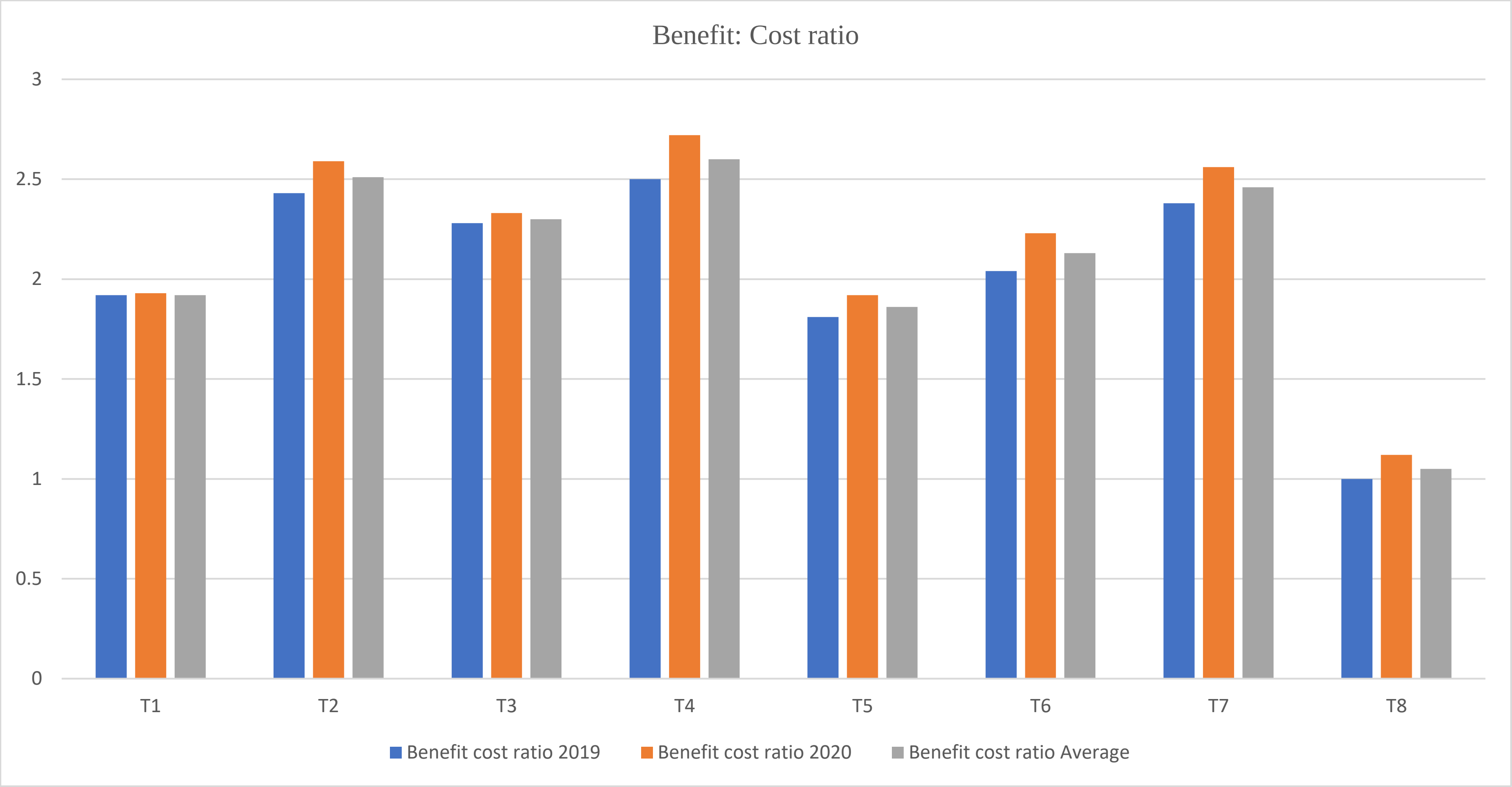


Fig. 4. 11 Effect of weed management combination on economics of soybean cultivation



4.8.3 Net returns

A glance of the data indicated that maximum net realization of (₹ 1,32,109 ha^{-1}) was obtained with the application of IC at 20 DAS *fb* hand weeding at 40 DAS (T_7), which was closely followed by Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4) and Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} – *fb* IC at 30 DAS (T_2). Whereas, the lower net realization (₹ 36,259 ha^{-1}) was obtained with unweeded control (T_8). This might be attributed to increased seed production and lower cultivation costs, particularly weed management, which increased the net return. This has a close conformity with Nagre *et al*. (2017) and Ahirwar *et al*. (2018) and Zain *et al*. (2020)

4.8.4 Benefit: Cost ratio (B:C)

Among different weed management treatments, the higher B:C ratio (2.56) was obtained with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS (T_4), which was comparable followed and by Sulfentrazone 48 SC @360 g a.i. ha^{-1} *fb* IC at 30 DAS). The unweeded control (T_8) recorded the lower B:C ratio (1.05). This finding is consistent with the findings of Venkatesha *et al*. (2008) and Ahirwar and Ahirwar (2023), who found that combining herbicide with handweeding/interculture was effective in controlling weed biomass, leading to in higher weed control efficiency during the early crop growth stages, producing maximum soybean yield and achieving maximum net return and B:C Ratio

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

The present investigation entitled "Evaluation of herbicides for weed management in soybean (*Glycine max* L.) and its residual effect on succeeding linseed (*Linum usitatissimum*)**"** was carried out during *kharif* seasons of 2019 and 2020 in the experimental farm of School of Agricultural Sciences (SAS), Nagaland University, Medziphema with the following objectives:

1. To study the effect of weed management practices on growth and yield of soybean
2. To evaluate the efficacy of weed management practices on associated weed flora in soybean
3. To determine the phytotoxicity of different herbicides on succeeding linseed
4. To study the relative economics of weed management practices in soybean and linseed cropping systems

The experiment consisting of eight treatments which was laid out in 'Randomised block design' and replicated thrice viz. T_1 : Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} pre-emergence, T_2 : Pendimethalin 30 EC @ 1.0 kg a.i. ha ha^{-1} *fb* IC at 30 DAS, T_3 : Imazethapyr 10 SL @ 100 g a.i. ha $^{-1}$ post emergence, 20 DAS, T_4 : Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence - *fb* IC at 30 DAS, T_5 : Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} - post emergence, 20 DAS, T_6 : Sulfentrazone 48 SC @ 360 g a.i. ha^{-1} (10 DAS) early post emergence– *fb* IC at 30 DAS, T_7 : IC at 20 DAS *fb* Hand weeding at 40 DAS and T_8 : Unweeded control. Data on crop and weeds as well as weed density, WCE, soil nutrient availability, soil microbial count and nutrient uptake by weeds and crops and economics were recorded as per the standard procedures. The salient research findings that were generated out of the experimentation to meet the objectives of the present study have been summarized below:

5.1 Effect of weed management on weed density

1. Results from the pooled data revealed that weed density of the grasses, broad leaf weeds and sedges were found to be the lowest among the herbicide applied with imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence - *fb* IC at 30 DAS for all the growth stages in both the years under study. The weed density of total weed was also found to be the lowest in treatment with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence -*fb* IC at 30 DAS for the two consecutive years in all stages of growth.
2. In case of weed density, total dry weight of weeds, the lowest dry weight density was found in Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS for all the growth stages for both the year.
3. Significantly, in case of weed control efficiency, Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS was found to be the most efficient treatment, whereas Sulfentrazone 48 SC @360 g a.i. ha^{-1} – post-emergence at 20 DAS was found to be having the lowest weed control efficiency at 20 DAS, while in rest of the growth stages Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} resulted the lowest.
4. The lowest weed index in soybean was found in IC at 20 DAS *fb* Hand weeding at 40 DAS and Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence - *fb* IC at 30 DAS among all the treatments.

5.2 Effect of weed management treatments on growth and yield parameters of the crops

1. The pooled data of the growth parameters *viz.,* plant height, number of primary branches per plant, plant dry weight leaf area index, dry matter content, number of root nodule per plant and nodule fresh and dry weight were found to be significantly highest in the treatment pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} *fb* IC at 30 DAS during 30 DAS during the 30 DAS, while in the later stages IC at 20 DAS *fb* hand weeding at 40 DAS recorded the higher values which is at par with

imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence -*fb* IC at 30 DAS under study.

2. Significantly, crop growth rate and relative growth rate were found highest with imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS treatment of soybean.
3. Yield attributes viz. number of pods per plant, pod length, number of seeds pod and pod weight was found significantly in IC at 20 DAS *fb* Hand weeding at 40 DAS which was at par with imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence- *fb* IC at 30 DAS. Similar, in case of grain yield, straw yield, harvest index and seed index of soybean where the significantly highest in all the characters were found in treatment with IC at 20 DAS *fb* Hand weeding at 40 DAS.
4. In case of linseed, highest plant population, dry matter and seed yield was observed in IC at 20 DAS *fb* Hand weeding at 40 DAS which was at par with imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence- *fb* IC at 30 DAS as compared to other treatments under studied.

5.3 Effect of herbicide residue on bioassay and soil properties

1. For all the test crop *viz.,* oat, mustard, cucumber, maize there was no significant differences of herbicide residue on root and shoot length of the crops
2. In case of soil pH and soil organic carbon effect of different weed management treatments were found to be non-significant. However, higher pH and SOC was found in case of IC at 20 DAS *fb* Hand weeding at 40 DAS treatment
3. Significantly, in case of available nitrogen and available phosphorous highest is found in IC at 20 DAS *fb* Hand weeding at 40 DAS treatment, however in case of available potassium no significant effect was observed in all the treatments studied.
4. Nitrogen, phosphorus and potassium uptake by weeds was also recorded highest in the unweeded (control) treatment. While the least was noted in IC at 20 DAS *fb*

Hand weeding at 40 DAS followed by imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence- *fb* IC at 30 DAS

5. Nitrogen, phosphorus and potassium uptake by crop is also highest in the IC at 20 DAS *fb* Hand weeding at 40 DAS treatment. Similar, trend was observed in case of seed and stover uptake of the crops.
6. Total nutrient uptake by crop was found to be the highest in IC at 20 DAS *fb* Hand weeding at 40 DAS for all the total nitrogen, phosphorus and potassium uptake.
7. In case of bacteria, fungi and total microbial count IC at 20 DAS *fb* Hand weeding at 40 DAS resulted the highest total soil microbial count whereas Pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} pre emergence resulted the highest actinomycetes count among all the treatments for both the years under study.

5.4 Economic analysis

- Inter cultivation at 20 DAS *fb* hand weeding at 40 DAS incurred highest cost of cultivation along with highest net return, however the benefit-cost ratio for both the years was found in the treatment with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* inter cultivation at 30 DAS.
- In case of linseed cultivation, the most benefitted weed management treatment was inter-cultivation at 20 DAS *fb* hand weeding at 40 DAS.

From the findings of the present investigation, the following conclusions may be drawn,

1. Weed management treatment with IC at 20 DAS *fb* hand weeding at 40 DAS which was at par with imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence- *fb* IC at 30 DAS may be adopted for the soybean-linseed crops for obtaining higher growth and yield attributing characters.
2. From the economic point of view the benefit-cost ratio for both the years was found highest in the treatment with Imazethapyr 10 SL @ 100 g a.i. ha^{-1} (10 DAS) early post emergence – *fb* IC at 30 DAS in soybean crop

Recommendation:

Based on the two years of field experimentation, it may be concluded that Imazethapyr 10 SL @ 100 g a.i. ha $^{-1}$ (10 DAS) early post emergence – *fb* inter cultivation at 30 DAS may be recommended for controlling weed in soybean- linseed as well as from the economic point of view.

CHAPTER VI

APPENDICES

APPENDIX-I

General cost of cultivation

(A) Soybean

Sl. No.	Particulars	Input/ Quantity	Rate (₹ unit^{-1})	Cost (₹ ha^{-1})
A	**Fixed cost**			
1	Field preparation			
	a. Ploughing	1 unit	₹ 1500	1500
	b. Harrowing	1 unit	₹ 1500	1500
	c. Bed preparation	3 mandays	₹ 300 /man/day	900
2	Manures and Fertilizer			
	a. FYM	10 t	₹ 1/kg	10000
	b. Nitrogen (Urea)	43.38 kg	₹ 320/50 kg bag	277.63
	c. Phophorus (SSP)	374.93 kg	₹ 420/50 kg bag	3149.41
	d. Potasium (MOP)	82.48 kg	₹ 980/50 kg bag	1616.6
	e. Application of manures and fertilizer	2 mandays	₹ 300 /man/day	600
3	Seed	70 kg	₹ 40	2800
4	Sowing	15	300/man/day	4500
5	Plant protection			
	a. Labour charges	12 mandays	₹ 300 /man/day	3600
	b. Insecticide			
	Chloropyriphos	4 litre	₹ 550/500ml	4400
	c. Fungicide			
	Carbendazim 50% WP	2 kg	200/100g	4000
	c. Rhizobium japonicum for seed treatment	350g	₹135 kg^{-1}	47
6	Harvesting, threshing drying and winnowing	20 mandays	₹300 /man/day	6000
Total cost (S.No. 1 to 5) (₹ ha^{-1})				**44891.00**

(B) Linseed

Sl. No.	Particulars	Input/ Quantity	Rate (₹ / unit)	Cost (₹ /ha)
1	Seed	40 kg	₹ 70/kg	2800
2	Sowing of Linseed	15 man days	₹ 300 /man/day	4500
3	Harvesting, threshing, drying and winnowing	20 man days	₹ 300 /man/day	6000
Total cost (S.No. 1 to 3) (₹ ha^{-1})				**13300.00**

APPENDIX-II

Total cost of cultivation for different weed management practices

Sl. No.	Particulars	Input/ Quantity	Rate (₹ unit^{-1})	Cost (₹ ha^{-1})
A	**Variable cost**			
T_1	Pendimethalin 30 EC	2.5 l/ha	₹ 676/liter	1690
	a. Labours required for herbicide application	2	₹ 300	600
			Total:	**₹ 2290.00**
T_2	Pendimethalin 30 EC	2.5 l/ha	₹ 676/kg	1690
	b. Hand weeding at 30 DAS	7	₹ 300	2100
	c. Labours required for herbicide application	2	₹ 300	600
			Total:	**₹ 4390.00**
T_3	a. Imazethapyr 10% SL	1000 ml	₹ 1350/ kg	1350
	c. Labours required for herbicide application	2	₹ 300	600
			Total:	**₹ 1950.00**
T_4	a. Imazethapyr 10% SL	1000 ml	₹ 1350/ kg	1350
	b. Interculture at 30 DAS	7 labours	₹ 300	2100
	c. Labours required for herbicide application	2 labours	₹ 300	600
			Total:	**₹ 4050.00**
T_5	a. Sulfentrazone 39.6% SC	360ml	₹ 4032/lit	1451
	c. Labours required for herbicide application	2 labours	₹ 300	600
			Total:	**₹ 2051.00**
T_6	a. Sulfentrazone 39.6% SC	360 ml	₹ 4,032	1451
	b IC at 30	7 labours	₹ 300	2100
	c.Labours required for herbicide application	2 labours	₹ 300	600
			Total:	**₹ 4151.00**
T_7	a. IC at 20	7 labours	₹ 300	2100
	b HW at 40	15 labours	₹ 300	4500
			Total:	**₹ 6600.00**
T_8	Weedy check			

APPENDIX-III

Effect of herbicide residue (by field bioassay) on root length of oat

Effect of herbicide residue on root length of oat (after 8 days)												
Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	7.12	7.23	7.18	8.36	9.02	8.69	9.02	8.94	8.98	8.56	9.36	8.96
T_2	7.49	8.11	7.80	7.98	8.64	8.31	8.64	8.79	8.72	8.73	9.07	8.90
T_3	7.71	7.71	7.71	8.86	9.52	9.19	9.52	9.80	9.66	8.34	8.05	8.19
T_4	6.77	7.05	6.91	7.92	8.58	8.25	8.58	8.99	8.78	8.11	7.39	7.75
T_5	7.25	7.37	7.31	7.83	8.49	8.16	8.49	8.70	8.60	7.40	8.99	8.20
T_6	7.41	7.41	7.41	8.56	9.22	8.89	9.22	9.63	9.42	8.71	7.29	8.00
T_7	7.33	7.81	7.57	8.14	8.80	8.47	8.80	9.07	8.94	7.80	7.33	7.57
T_8	6.76	6.82	6.79	7.91	8.57	8.24	8.57	8.84	8.70	7.25	7.18	7.22
SEm±	***0.33***	***0.32***	***0.23***	***0.36***	***0.36***	***0.26***	***0.36***	***0.44***	***0.29***	***0.74***	***0.59***	***0.47***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

APPENDIX-IV

Effect of herbicide residue (by field bioassay) on shoot length of oat

Effect of herbicide residue on shoot length of oat (after 8 days)												
Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	9.70	8.88	9.29	10.44	10.46	10.45	8.96	9.67	9.32	9.25	10.00	9.62
T_2	8.71	8.84	8.77	10.11	10.23	10.17	9.41	10.12	9.76	8.58	7.79	8.19
T_3	7.85	7.90	7.87	9.08	9.20	9.14	9.92	10.63	10.27	10.20	10.95	10.58
T_4	8.99	9.39	9.19	10.52	9.86	10.19	9.66	10.37	10.02	9.06	9.30	9.18
T_5	7.45	8.69	8.07	10.00	9.93	9.97	8.85	9.56	9.21	9.14	9.89	9.51
T_6	9.00	8.90	8.95	10.30	10.42	10.36	11.14	9.04	10.09	10.95	11.45	11.20
T_7	9.18	9.21	9.20	10.71	10.83	10.77	10.06	9.40	9.73	9.35	8.30	8.82
T_8	8.00	8.48	8.24	9.78	9.90	9.84	9.03	9.75	9.39	9.32	10.07	9.70
SEm±	***0.70***	***0.62***	***0.47***	***0.62***	***0.74***	***0.48***	***1.06***	***1.11***	***0.77***	***0.96***	***0.89***	***0.65***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

APPENDIX-V

Effect of herbicide residue (by field bioassay) on root length of mustard

Effect of herbicide residue on root length of mustard (after 8 days)												
Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	3.55	3.41	3.48	3.16	3.86	3.51	3.18	3.24	3.21	4.26	4.28	4.27
T_2	3.44	3.32	3.38	3.24	3.94	3.59	3.18	4.01	3.59	4.20	4.26	4.23
T_3	2.84	3.48	3.16	3.21	3.89	3.55	3.25	3.21	3.23	4.28	4.30	4.29
T_4	3.51	4.02	3.77	3.35	3.74	3.54	3.30	3.73	3.52	4.28	4.27	4.27
T_5	3.39	3.92	3.66	3.21	3.67	3.44	3.33	3.19	3.26	4.24	4.22	4.23
T_6	3.47	3.74	3.61	3.30	3.48	3.39	3.67	4.00	3.83	4.27	4.30	4.29
T_7	3.55	3.96	3.76	3.34	3.62	3.48	3.22	3.74	3.48	4.28	4.30	4.29
T_8	2.36	3.00	2.68	3.06	3.13	3.10	3.17	3.18	3.18	3.91	3.88	3.90
SEm±	***0.56***	***0.46***	***0.36***	***0.07***	***0.63***	***0.31***	***0.10***	***0.27***	***0.14***	***0.18***	***0.17***	***0.12***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

APPENDIX-VI

Effect of herbicide residue (by field bioassay) on shoot length of mustard

Effect of herbicide residue on shoot length of mustard (after 8 days)												
Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	4.14	4.41	4.27	4.82	4.47	4.64	4.37	4.38	4.38	4.57	4.74	4.66
T_2	4.34	4.63	4.48	4.53	4.66	4.60	4.37	4.34	4.36	4.59	4.41	4.50
T_3	4.59	4.44	4.52	4.48	4.65	4.57	4.38	4.38	4.38	4.42	4.43	4.42
T_4	3.53	4.63	4.08	4.43	4.50	4.47	4.36	4.39	4.38	4.79	4.39	4.59
T_5	4.56	4.45	4.51	4.50	4.48	4.49	4.39	4.37	4.38	4.39	4.38	4.38
T_6	4.33	4.39	4.36	4.57	4.51	4.54	4.33	4.39	4.36	4.37	4.38	4.38
T_7	4.45	4.43	4.44	4.01	4.50	4.26	4.38	4.37	4.38	4.38	4.70	4.54
T_8	3.73	3.76	3.75	4.14	4.13	4.14	4.38	4.36	4.37	4.25	4.38	4.32
SEm±	***0.30***	***0.22***	***0.19***	***0.21***	***0.19***	***0.14***	***0.08***	***0.07***	***0.05***	***0.22***	***0.17***	***0.14***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

APPENDIX-VII

Effect of herbicide residue (by field bioassay) on root length of cucumber

Effect of herbicide residue on root length of cucumber (after 8 days)												
Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	4.55	4.52	4.54	5.16	4.97	5.06	5.69	5.79	5.74	7.22	7.16	7.19
T_2	5.02	4.89	4.95	4.91	5.05	4.98	5.66	5.92	5.79	5.78	6.56	6.17
T_3	5.35	5.01	5.18	4.58	4.59	4.58	5.56	5.66	5.61	6.82	6.23	6.52
T_4	5.15	5.47	5.31	5.04	5.19	5.11	6.16	6.53	6.34	6.62	6.39	6.51
T_5	4.33	4.35	4.34	4.59	4.90	4.74	5.69	5.26	5.47	6.64	6.34	6.49
T_6	5.28	5.25	5.27	5.02	4.99	5.01	5.92	5.92	5.92	6.69	7.10	6.89
T_7	4.87	5.42	5.15	5.23	5.50	5.37	5.82	5.56	5.69	6.64	6.22	6.43
T_8	3.96	4.81	4.39	4.85	4.96	4.91	5.19	5.16	5.18	6.26	6.36	6.31
SEm±	***0.34***	***0.47***	***0.29***	***0.20***	***0.29***	***0.17***	***0.39***	***0.35***	***0.26***	***0.28***	***0.37***	***0.23***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

APPENDIX-VIII

Effect of herbicide residue (by field bioassay) on shoot length of cucumber

Effect of herbicide residue on root length of cucumber (after 8 days)												
Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	7.18	6.83	7.01	7.81	7.66	7.74	7.48	7.42	7.45	7.48	7.93	7.71
T_2	7.19	6.58	6.89	7.56	8.41	7.99	8.14	8.26	8.20	8.14	7.98	8.06
T_3	7.02	6.91	6.97	8.19	8.37	8.28	7.25	7.18	7.22	7.25	7.28	7.27
T_4	7.22	7.03	7.12	8.01	8.16	8.08	7.78	7.68	7.73	7.30	7.64	7.47
T_5	7.03	7.13	7.08	7.63	7.43	7.53	8.33	8.14	8.24	7.41	8.03	7.72
T_6	6.91	6.55	6.73	7.53	7.67	7.60	8.23	7.58	7.91	7.82	7.93	7.87
T_7	7.78	7.08	7.43	7.45	7.30	7.37	8.42	7.71	8.07	8.42	8.47	8.45
T_8	6.58	6.89	6.74	7.23	7.07	7.15	7.03	5.95	6.49	7.31	7.70	7.51
SEm±	***0.35***	***0.36***	***0.25***	***0.37***	***0.51***	***0.32***	***0.51***	***0.69***	***0.43***	***0.36***	***0.39***	***0.26***
CD (P=0.05)	***NS***	***NS***	***NS***	***1.86***	***2.06***	***1.32***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

APPENDIX-IX

Effect of herbicide residue (by field bioassay) on root length of maize

Effect of herbicide residue on root length of maize (after 8 days)												
Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	8.22	8.30	8.26	7.32	6.94	7.13	8.83	9.00	8.92	10.37	10.69	10.53
T_2	8.64	7.81	8.23	7.63	8.04	7.83	8.57	8.87	8.72	9.37	9.31	9.34
T_3	8.22	8.81	8.51	6.74	6.81	6.77	8.46	9.17	8.81	11.89	10.06	10.98
T_4	7.39	8.26	7.82	6.88	7.01	6.95	8.53	8.47	8.50	10.85	9.85	10.35
T_5	8.08	8.07	8.08	6.75	6.99	6.87	8.60	8.78	8.69	9.87	9.87	9.87
T_6	8.25	9.16	8.70	7.18	7.16	7.17	8.51	8.77	8.64	9.92	9.92	9.92
T_7	8.14	8.87	8.51	7.20	7.31	7.26	8.73	8.80	8.77	9.87	9.87	9.87
T_8	7.93	8.05	7.99	7.01	7.12	7.07	8.07	8.14	8.11	8.75	8.80	8.78
SEm±	***0.53***	***0.63***	***0.41***	***0.24***	***0.30***	***0.19***	***0.38***	***0.27***	***0.24***	***0.55***	***7.42***	***3.72***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

APPENDIX-X

Effect of herbicide residue (by field bioassay) on shoot length of maize

Effect of herbicide residue on shoot length of maize (after 8 days)												
Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**120 DAS**		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
T_1	5.97	6.82	6.39	6.53	6.37	6.45	7.09	6.93	7.01	6.14	6.34	6.24
T_2	4.82	5.21	5.01	5.38	5.77	5.57	7.17	6.63	6.90	6.14	6.38	6.26
T_3	5.37	5.70	5.54	5.93	6.26	6.10	6.49	6.82	6.66	6.09	6.52	6.30
T_4	5.15	6.00	5.58	5.71	6.56	6.14	6.27	7.12	6.70	5.37	5.72	5.55
T_5	5.82	6.67	6.24	5.23	5.80	5.52	6.94	7.79	7.36	6.19	6.20	6.20
T_6	6.03	5.78	5.91	6.59	6.34	6.47	7.15	6.90	7.03	6.23	6.26	6.25
T_7	5.46	6.31	5.88	6.02	6.87	6.44	6.58	7.43	7.00	6.42	6.30	6.36
T_8	4.57	4.97	4.77	5.13	5.53	5.33	5.69	6.09	5.89	5.77	5.85	5.81
SEm±	***0.41***	***0.49***	***0.32***	***0.39***	***0.55***	***0.33***	***0.40***	***0.48***	***0.32***	***0.44***	***0.39***	***0.29***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

CHAPTER VII

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