MANAGING TILLAGE, IRRIGATION WATER AND SOWING METHODS FOR PRODUCTION OF WHEAT (*Triticum aestivum* L.) UNDER SHAMBAT CONDITIONS

By

MOHAMED ELHAFIZ ADAM MOHAMED

B.Sc. Agric. (Hons.) U. of K. 1991

M.Sc. (Agric.) U. of K. 1995

A Thesis

Submitted to the University of Khartoum in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

Supervisor: Dr. Abdel Moneim Elamin Mohamed

Department of Agricultural Engineering

Faculty of Agriculture

University of Khartoum

November 2004
DEDICATION

This work is dedicated to:
My parents, children and wife
My brother Nor Eldin and my late brother Elrayah
My late niece Rogia

My uncles, Tigani, Hamza and Ahmed Hamed
as well as;
My late uncles, Ahmed Hassan Hamad and
Mairghani Wed Elfaki

Mohamed Elhafiz
ACKNOWLEDGMENT

It is a great pleasure for me to express my deep thanks and gratitudes to my supervisor, Dr. Abdel Moneim Elamin Mohamed for his close follow-up, encouragement, guidance and infinite patience. Thanks are also due to the staff of the Department of Agricultural Engineering for their help and cooperation throughout the course of this work.

Appreciable help was lent by members of the Department of Agricultural Engineering, University of Gezira and the Agricultural Bank, Khartoum, as well as many of my colleagues here and there, and I would therefore sincerely like to convey my great thanks to them.

Finally, thanks are due to the University of Dongola for financing this study clearly to the end.
ABSTRACT

An experiment was conducted for three successive seasons (2000/01 – 2002/03) in the Demonstration Farm of the Faculty of Agriculture, University of Khartoum, Shambat to investigate the effect of tillage (T), irrigation water amount (W), and sowing method (S) on wheat crop yield (Elneelein Variety). Seed lot for each season was brought from Hudeiba Research Station.

Tillage treatments constituted five land preparation systems, viz.; offset disc harrow, ridger, chisel plough, disc plough, and no-till (T1 to T5). Irrigation water amounts were determined with aid of the modified Penman (1977) method in terms of crop evapotranspiration (ETc%) and comprised three levels, namely; 100%, 80%, and 60% ETc (W1, W2 and W3). Sowing methods included flat and ridge sowing (S1 and S2).

The experiment was laid in a strip-split-plot design with three replications. Tillage treatments were assigned as vertical factor, water amounts as horizontal factor and sowing methods as subplot factor. Irrigation water amount was measured using a 90° V-notch weir.
Parameters pertaining to soil physical properties, infiltration characteristics, machine performance, crop agronomic attributes, as well as water utilization efficiency were assessed and processed.

Results obtained revealed that tillage method and depth did not induce any significant variations in soil bulk density (g/cm³) and porosity (%) in all seasons. However, disc plough and ridger profiles recorded greater initial infiltration rates (22.44 and 20.22 cm/h), while no-till plots recorded the least value (11.30 cm/h) in all seasons. Basic infiltration rate was reached earlier (35 min.) in disc plough and no-till profiles. Disc plough also recorded the greatest total draft (11.00 kN) and unit draft (6.50 N/cm²) requirements as well as fuel consumption rates (5.9 ℓ/h and 12.73 ℓ/ha).

No-till system and the stressed watering regimes (60% ETc) were significantly (P < 0.05) inferior with respect to agronomic attributes of the crop in comparison to its corresponding treatments, and that, the 100% and 80% ETc regimes were statistically similar for almost all parameters in all seasons.

Mean maximum and minimum grain yields (t/ha) were 2.89 and 1.91 as corresponding to plough-till and no-till, respectively. However, both ridger and offset disc harrow systems were almost comparable with respect to crop yield and averaged 2.94 t/h.

On the other hand, average grain yields, over all seasons were 2.90, 2.73 and 2.03 t/h for the 100%, 80%, and 60% ETc water regimes, respectively.

Flat sowing was significantly (P < 0.05) superior to ridge sowing in terms of number of effective tillers/plant (1.58 vs. 1.09), grain yield (2.85 vs. 2.54 t/ha), and harvest index (42.50 vs. 41.20%) but was similar to it in the remaining attributes, throughout the seasons.
Water use efficiency (WUE) was maximized (0.43 kg/m$^3$) when 80% ET$_c$ watering regime was applied, while the full watering regime (100% ET$_c$) gave the least value (0.36 kg/m$^3$).

Based on these results, it is evident that, maximum yield of wheat would be obtained with plough-till, based on either ridger or offset disc harrow systems, flat sowing as well as irrigation at 80% ET$_c$. 
π

(03/2002 – 01/2000) \( V \)- notch 360°/20 سم 

\[ \text{أ diversas} \] 

\[ \text{(V-notch) } \]

\[ \text{قد} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]

\[ \text{و} \]
لا يوجد نص يمكن قراءته بشكل طبيعي من الصورة المقدمة.
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DEDICATION</strong></td>
<td>i</td>
</tr>
<tr>
<td><strong>ACKNOWLEDGEMENT</strong></td>
<td>ii</td>
</tr>
<tr>
<td><strong>ABSTRACT</strong></td>
<td>iv</td>
</tr>
<tr>
<td><strong>ARABIC ABSTRACT</strong></td>
<td></td>
</tr>
<tr>
<td><strong>CHAPTER ONE: INTRODUCTION</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>CHAPTER TWO: LITERATURE REVIEW</strong></td>
<td>6</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>6</td>
</tr>
<tr>
<td>2.2 Concept and importance of tillage</td>
<td>8</td>
</tr>
<tr>
<td>2.3 Tillage systems</td>
<td>10</td>
</tr>
<tr>
<td>2.4 Implements for soil tillage</td>
<td>12</td>
</tr>
<tr>
<td>2.4.1 Primary tillage implements</td>
<td>12</td>
</tr>
<tr>
<td>2.4.1.1 Disc plough</td>
<td>13</td>
</tr>
<tr>
<td>2.4.1.2 Chisel plough</td>
<td>14</td>
</tr>
<tr>
<td>2.4.2 Secondary tillage implements</td>
<td>14</td>
</tr>
<tr>
<td>2.4.2.1 Disc harrows</td>
<td>15</td>
</tr>
<tr>
<td>2.4.2.2 Ridgers</td>
<td>16</td>
</tr>
<tr>
<td>2.5 Effect of tillage on seedbed characteristics</td>
<td>17</td>
</tr>
<tr>
<td>2.5.1 Effect of tillage on soil physical properties</td>
<td>19</td>
</tr>
<tr>
<td>2.5.2 Effect of tillage on infiltration</td>
<td>20</td>
</tr>
<tr>
<td>2.5.3 Effect of tillage on bulk density</td>
<td>26</td>
</tr>
<tr>
<td>2.5.4 Tillage and soil compaction</td>
<td>28</td>
</tr>
<tr>
<td>2.6 Machine performance</td>
<td>29</td>
</tr>
<tr>
<td>2.6.1 Traction, rear wheel (slippage), and energy consumption</td>
<td>29</td>
</tr>
<tr>
<td>2.6.2 Fuel consumption</td>
<td>34</td>
</tr>
<tr>
<td>2.6.3 Field capacity and operation efficiency</td>
<td>36</td>
</tr>
<tr>
<td>2.7 Effect of tillage on crop water requirements (CWR) or crop evapotranspiration ($ET_c$) or consumptive use ($C_w$, $U$)</td>
<td>38</td>
</tr>
<tr>
<td>2.7.1 Concept and importance</td>
<td>38</td>
</tr>
<tr>
<td>2.7.1.1 Reference crop evapotranspiration, $ET_o$</td>
<td>39</td>
</tr>
<tr>
<td>2.7.1.2 Crop factor ($K_c$)</td>
<td>40</td>
</tr>
</tbody>
</table>
2.7.2 Methods for calculating ET\textsubscript{crop} based on ET\textsubscript{o} 41
2.7.2.1 Blaney-criddle method 41
2.7.2.2 Penman method 42
2.7.2.3 Radiation method 44
2.7.2.4 Pan evaporation method 44
2.8 Effect of tillage and seedbed practices on wheat production 46
2.8.1 Effect of tillage and seedbed practices 46
2.8.2 Effect of irrigation practices 49
2.9 Effect of tillage and irrigation practices on Sudan wheat production 53

CHAPTER THREE: MATERIALS AND METHODS 59
3.1 Location 59
3.2 Design and layout of the experiment 59
3.3 Cultural practices 60
3.3.1 Tillage and seeding 60
3.3.2 Irrigation water measurement and application 66
3.3.3 Cultural practices 69
3.4 Determination of soil physical properties 69
3.4.1 Determination of soil moisture content (%) 69
3.4.2 Determination of soil bulk density (g/cm\textsuperscript{3}) and % pore space (porosity) 70
3.4.3 Determination of infiltration rate (l/t) 71
3.5 Machine performance parameters 72
3.5.1 Field capacity of machine (C, ha/h) 72
3.5.1.1 Working speed (S, km/h) 72
3.5.1.2 Working (ploughing) width (w, m) 72
3.5.1.3 Field efficiency (e, %) 72
3.5.1.4 Ploughing depth (cm) 73
3.5.2 Fuel consumption (l/h, l/ha) 74
3.5.3 Power-related parameters 74
3.5.3.1 Total draft (D, kN) 74
3.5.3.2 Travel reduction (%) 77
3.6 Growth and yield components  

Page  

3.6.1 Growth components  
3.6.1.1 Plant population (plants/m²)  

3.6.1.2 Plant height (cm)  
3.6.1.3 Leaf area index (LAI)  
3.6.1.4 Leaf turgidity (%)  
3.6.1.5 Number of effective tillers/plant  
3.6.1.6 Number of tillers/m²  

3.6.1.7 Plant population at harvest (plants/m²)  

3.6.2 Yield and yield Components  
3.6.2.1 Number of spikelets/spike  
3.6.2.2 Number of grains/spike  
3.6.2.3 Weight of grains/spike (g)  
3.6.2.4 Thousand-grain weight (g)  
3.6.2.5 Weight of spikes/plant (g)  

3.6.2.6 Number of aborted spikelets/spike  

3.6.2.7 Harvest index (H.I. %)  
3.6.2.8 Grain yield (ton/ha)  

3.7 Water use efficiency (WUE, kg/m³)  

CHAPTER FOUR: RESULTS  

4.1 Effect of tillage on physical properties of soil  
4.1.1 Effect on soil moisture content (db%)  
4.1.2 Effect on bulk density (g/cm³)  
4.1.3 Effect on porosity (%)  
4.1.4 Effect on infiltration characteristics  

4.2 Machine performance  

4.3 Effect of tillage methods (T), water regimes (W, ETc %), method of sowing (S), and three interaction on growth components of wheat  

4.3.1 Effects on plant population (plants/m²)  
4.3.1.1 Plant population at emergence  
4.3.1.2 Plant population at harvest  

4.3.2 Effects on plant height (cm)  
4.3.2.1 Plant height, 6 weeks after sowing
Page
4.3.2.2 Plant height, 9 weeks after sowing 110
4.3.2.3 Plant height, 12 weeks after sowing 111
4.3.2.4 Plant height at harvest 112
4.3.3 Effect on leaf area index (LAI) 116
4.3.4 Effect on leaf turgidity (LT, %) 122
4.3.5 Effect on number of tillers 122
4.3.5.1 Number of tillers/plant 122
4.3.5.2 Number of tillers/m² 126
4.4 Effect of tillage (T), water regimes (W, ETc %), method of
  sowing (S), and their interaction on yield and yield components of
  wheat 130
4.4.1 Effect on number of fertile spikelets/spike 130
4.4.2 Effects on number of seeds/spike 137
4.4.3 Effects on weight of spike (g) 139
4.4.4 Effects on number of seeds/plant 143
4.4.5 Effects on weight of seeds/plant (g) 147
4.4.6 Effects on 1000-grains weight (g) 147
4.4.7 Effects on total grain yield (t/ha) 148
4.4.8 Effects on harvest index (H.I, %) 152
4.5 Water use efficiency (WUE, kg/m³) 157

CHAPTER FIVE: DISCUSSION 159
5.1 Status of soil moisture content (SMC) 159
5.2 Effect of tillage methods on bulk density (g/cm³) and
  porosity (%) 160
5.3 Effect of tillage methods on infiltration characteristics 162
5.4 Machine performance 164
5.4.1 Field capacity (C, ha/h) 164
5.4.2 Field efficiency (e, %) 165
5.4.3 Fuel consumption (l/h and l/ha) 165
5.4.4 Drive wheel slippage (%) 166
5.4.5 Draft requirements (kN) 167

5.5 Effect of tillage methods, watering regimes, and method of
  sowing on growth components of wheat 168
Page
5.5.1 Effect on plant population (plants/m²) 168
5.5.1.1 Population at emergence 168
5.5.1.2 Population at harvest 168
5.5.2 Effect on plant height (cm) 169
5.5.3 Effect on leaf area index (LAI) 170
5.5.4 Effect on number of effective tillers 172
5.5.5 Effect on leaf turgidity (LT, %) 173
5.6 Effect of tillage methods, watering regimes, and method of sowing on yield and its components 174
5.6.1 Effect on number of fertile spikelets, and number of seeds per spike 174
5.6.2 Effect on weight of spike (g) 175
5.6.3 Effect on number, and weight (g) of seeds/plant 177
5.6.4 Effect on 1000-grain weight (g) 177
5.6.5 Effect on total grain yield (t/ha) 178
5.6.6 Effect on harvest index (HI, %) 183
5.7 Effect of watering regimes on water use efficiency (WUE, kg/m³) 184

CONCLUSIONS AND RECOMMENDATIONS 186
1. Conclusions 186
2. Recommendations 187
REFERENCES 189
APPENDICES 217
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1a</td>
<td>Residual soil moisture content (% db) in flat beds of the different tillage treatments, receiving different water regimes (% ETc) at three soil depths, 1st season (2000/01).</td>
<td>84</td>
</tr>
<tr>
<td>4.1b</td>
<td>Residual soil moisture content (% db) in flat beds of the different tillage treatments, receiving different water regimes (% ETc) at three soil depths, 2nd season (2001/02).</td>
<td>85</td>
</tr>
<tr>
<td>4.1c</td>
<td>Residual soil moisture content (%db) in flat profiles of different tillage methods, averaged over 0.60 m soil depth, on season -, overseason -, and overall - basis.</td>
<td>86</td>
</tr>
<tr>
<td>4.2a</td>
<td>Effect of tillage methods as bulk density (g/cm³) and three soil depths; 1st season (2000/01).</td>
<td>89</td>
</tr>
<tr>
<td>4.2b</td>
<td>Effect of tillage methods as bulk density (g/cm³) and three soil depths; 2nd season (2001/02).</td>
<td>90</td>
</tr>
<tr>
<td>4.3a</td>
<td>Effect of tillage methods as porosity (%) and three soil depths; 1st season (2000/01).</td>
<td>91</td>
</tr>
<tr>
<td>4.3b</td>
<td>Effect of tillage methods as porosity (%) and three soil depths; 2nd season (2001/02).</td>
<td>92</td>
</tr>
<tr>
<td>4.4a</td>
<td>Draft-related parameters of the different tillage implements used in the study.</td>
<td>97</td>
</tr>
<tr>
<td>4.4b</td>
<td>Draft-related parameters of the different</td>
<td>98</td>
</tr>
</tbody>
</table>
tillage implements used in the study.

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5a</td>
<td>Effect of tillage methods on growth components of wheat, 1st season (2000/01).</td>
<td>101</td>
</tr>
<tr>
<td>4.5b</td>
<td>Effect of water amount on growth components of wheat, 1st season (2000/01).</td>
<td>102</td>
</tr>
<tr>
<td>4.5c</td>
<td>Effect of tillage methods on growth components of wheat, 2nd season (2001/02).</td>
<td>103</td>
</tr>
<tr>
<td>4.5d</td>
<td>Effect of water amount on growth components of wheat, 2nd season (2001/02).</td>
<td>104</td>
</tr>
<tr>
<td>4.5e</td>
<td>Effect of tillage methods on growth components of wheat, 3rd season (2002/03).</td>
<td>105</td>
</tr>
<tr>
<td>4.5f</td>
<td>Effect of water amount on growth components of wheat, 3rd season (2002/03).</td>
<td>106</td>
</tr>
<tr>
<td>4.6</td>
<td>Interaction effect (W x S) between water regimes (W, ETc%) and method of sowing (s) on plant population at harvest (plants/m²).</td>
<td>109</td>
</tr>
<tr>
<td>4.7</td>
<td>Interaction effect (T x W) between tillage methods (T) and water regimes (W, ETc%) on LAI.</td>
<td>121</td>
</tr>
<tr>
<td>4.8a</td>
<td>Interaction effect (T x W) between tillage methods (T) and water regimes (W, ETc%) on number of effect tillers/plant.</td>
<td>127</td>
</tr>
<tr>
<td>4.8b</td>
<td>Interaction effect (T x S) between water regimes (W, ETc%) x method of sowing (S) on number of effect tillers/m².</td>
<td>129</td>
</tr>
<tr>
<td>4.9a</td>
<td>Effect of tillage methods on yield and yield components of wheat, 1st season (2000/01).</td>
<td>131</td>
</tr>
<tr>
<td>Table</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>4.9b</td>
<td>Effect of water amounts on yield and yield components of wheat, 1st season (2000/01).</td>
<td>132</td>
</tr>
<tr>
<td>4.9c</td>
<td>Effect of tillage methods on yield and yield components of wheat, 2nd season (2001/02).</td>
<td>133</td>
</tr>
<tr>
<td>4.9d</td>
<td>Effect of water amounts on yield and yield components of wheat, 2nd season (2001/02).</td>
<td>134</td>
</tr>
<tr>
<td>4.9e</td>
<td>Effect of tillage methods on yield and yield components of wheat, 3rd season (2002/03).</td>
<td>135</td>
</tr>
<tr>
<td>4.9d</td>
<td>Effect of water amounts on yield and yield components of wheat, 3rd season (2002/03).</td>
<td>136</td>
</tr>
<tr>
<td>4.10</td>
<td>Interaction effect (T x W) between tillage method (T) and water regimes (W, ETc %) on number of spikelets/spike.</td>
<td>138</td>
</tr>
<tr>
<td>4.11</td>
<td>Total amount of water (m3/ha/season)applied at each season as related to conventional amount at the Gezira scheme.</td>
<td>158</td>
</tr>
</tbody>
</table>
**LIST OF FIGURES**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Layout of the experiment.</td>
<td>61</td>
</tr>
<tr>
<td>4.1</td>
<td>Soil moisture content (% db) of the experimental site just before land preparation at the three soil depths, in the three seasons (2000-2003).</td>
<td>83</td>
</tr>
<tr>
<td>4.2</td>
<td>Mean bulk density (g/cm$^2$) as affected by tillage methods (T) on per season and over-season basis.</td>
<td>88</td>
</tr>
<tr>
<td>4.3a</td>
<td>Effect of tillage methods (T) on filtration rate (cm/h), 1$^{st}$ season (2000/01).</td>
<td>94</td>
</tr>
<tr>
<td>4.3b</td>
<td>Effect of tillage methods (T) on filtration rate (cm/h), 2$^{nd}$ season (2001/02).</td>
<td>95</td>
</tr>
<tr>
<td>4.4a</td>
<td>Plant height at harvest (cm), 1$^{st}$ season (2000/01).</td>
<td>113</td>
</tr>
<tr>
<td>4.4b</td>
<td>Plant height at harvest (cm), 2$^{nd}$ season (2001/02).</td>
<td>114</td>
</tr>
<tr>
<td>4.4c</td>
<td>Plant height at harvest (cm), 3$^{rd}$ season (2002/03).</td>
<td>115</td>
</tr>
<tr>
<td>4.5a</td>
<td>Leaf area index (LAI), 1$^{st}$ season (2000/01).</td>
<td>117</td>
</tr>
<tr>
<td>4.5b</td>
<td>Leaf area index (LAI), 2$^{nd}$ season (2001/02).</td>
<td>118</td>
</tr>
<tr>
<td>4.5c</td>
<td>Leaf area index (LAI), 3$^{rd}$ season (2002/03).</td>
<td>119</td>
</tr>
<tr>
<td>4.6a</td>
<td>Number of effective tillers/plant, 1$^{st}$ season (2000/01).</td>
<td>123</td>
</tr>
</tbody>
</table>
4.6b Number of effective tillers/plant, 2nd season (2001/02).

4.6c Number of effective tillers/plant, 3rd season (2002/03).

Figure Title Page

4.7a Weight of spike (g), 1st season (2000/01). 140

4.7b Weight of spike (g), 2nd season (2001/02). 141

4.7c Weight of spike (g), 3rd season (2002/03). 142

4.8a Number of seeds/plant, 1st season (2000/01). 144

4.8b Number of seeds/plant, 2nd season (2001/02). 145

4.8c Number of seeds/plant, 3rd season (2002/03). 146

4.9a Total grain yield (t/ha), 1st season (2000/01). 149

4.9b Total grain yield (t/ha), 2nd season (2001/02). 150

4.9c Total grain yield (t/ha), 3rd season (2002/03). 151

4.10a Harvest index (HI, %), 1st season (2000/01). 154

4.10b Harvest index (HI, %), 2nd season (2001/02). 155

4.10c Harvest index (HI, %), 3rd season (2002/03). 156

4.11 Effect of water amount (ETc%) on grain yield (t/ha) and water use efficiency, WUE (kg/m²) in all farms. 158
**LIST OF PLATES**

<table>
<thead>
<tr>
<th>Plate</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Ridger</td>
<td>63</td>
</tr>
<tr>
<td>3.2</td>
<td>Chisel plough</td>
<td>64</td>
</tr>
<tr>
<td>3.3</td>
<td>Disc plough</td>
<td>65</td>
</tr>
<tr>
<td>3.4</td>
<td>Applying total crop water requirements at farm</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>level using 90° V-notch weir.</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Dynamometer</td>
<td>75</td>
</tr>
</tbody>
</table>
The potentially productive agricultural land in the world is either inaccessible, too steep, too shallow, too dry, or too wet. However, the currently cultivated part of it is only 11% of the earth’s land which produces 97% of our food. Only 15% of this area is under irrigation with waterlogging, salinization and infertility as major problems particularly in arid and semi-arid areas (FAO, 1995). Deteriorated soil structure and compaction are common outcomings of frequent use or misuse of machinery particularly during tillage operations, as well as higher rates of irrigation water (or rainfall). Surface crusting, sealing, swelling, entrapment of air, washing and orientation of fine particles into the soil matrix, restriction of air and water flow at wetting, mechanical impedance, reduced infiltration, low water holding capacity, pores discontinuity (high bulk density) that hinders root and water movement, increased soil detachability and erosion, low seedling emergence rate, shallow root establishment, high water and nutrient stress on plant growth, and final yield reduction are major ill-effects that would inevitably be encountered. Nevertheless, tillage remains to be the most, if not the only effective mean to alleviate such discrepancies in addition to establishing the seed-soil contact despite the fact that 90% of the soil surface can be traversed by tractor wheels during tillage operations.

The mode and intensity of tillage depends on soil type and the related constraints to crop production. An effective tillage system creates soil conditions favourable for water infiltration, seed
germination, plant emergence, and early growth and root development, which finally result in economical crop yield.

The recognition of the need to protect the limited fertile topsoil from erosion and degradation has led to the development of a wide range of tillage systems, generally referred to as conservation tillage for erosion control as well as energy and soil moisture conservation.

Water for crop production is generally obtained from one of three sources; rainfall, surface irrigation supplies, and ground water. These supplies are usually intermittent compared to the continuous demands of crop. Water use of crops is influenced by climatic, plant, soil, and cultural factors. Therefore, when water supply is limited, or when irrigation contribution to food is to be increased, continuous research for management practices that would increase the water use efficiency (WUE) becomes crucial.

Inadequacy or unreliability of total rainfall as well as employment of socio-economic or technical-economic reasons may justify irrigation for the production of maximum returns/unit of the scarce input, which in most instances, is water. However, FAO (1995) and others reported that, an irrigation regime that provides soil moisture for maximum crop growth and yield per unit area would be unlikely to produce maximum output per unit of water (WUE). They concluded that, yield could be a product of three factors viz. usable water, WUE, and harvest index. However, it is difficult to match supplies exactly to reasonable demands of crops. A common management problem for a farmer is to, practically obtain a profitable cropping pattern at a specific discharge. But, to achieve maximum plant growth, soil moisture levels should fluctuate only within a fairly narrow range between field capacity and permanent
wilting point, as costs of irrigation are due mainly to improper use of water.

It is difficult to apply water uniformly with surface irrigation as soil conveys and infiltrates water over the field. As long as the water supply is smaller than soil infiltrability, water infiltrates as fast as it is supplied, and the supply rates determines the infiltration rate. Conversely, the profile characteristics tend to determine the infiltration rate at greater water supplies.

Up to 66% of the cropped area in the world is used for cereals, with wheat ranks the top (FAO, 1995). Wheat yield is fairly determined by the amount of water (including water stored in rootzone) in the top 900 mm of soil, and the crop roots too deeply when water is scarce. Generally, crop response to water supply is a complex of physical, biological, and biochemical processes.

Irrigation in the Sudan started by pumps to substitute traditional methods, in 1904 at Zeidab scheme. Sinnar dam started in 1925 to irrigate 44100 ha (105000 feds.) at Gezira by gravity. Both systems constituted more than 95% of the irrigation practices since wheat is a fully irrigated, fully mechanized crop (Farah, 1995).

Average per capita consumption of wheat per year rose from 10.5 kg in 1960, to about 33 kg in 1993. The area devoted to wheat is around 400,000 ha annually (Faki, 1995). To achieve self-sufficiency, area expansion in the existing irrigation schemes is one of the major instruments used. However, factors relating to soil management and the environment are major constraints to its cultivation, while soil tillage and irrigation water management are major items affecting its establishment.
Dawelbeit (1995) and other researchers concluded that, any research in wheat mechanization should be focussed on two main issues; input optimization and machinery selection (operation efficiency). The cracking heavy clay vertisols, the major wheat production soils in Sudan, are characterized by being hard to work when too dry, and very muddy for traction when wet (Dawelbeit, 1995).

Tillage methods for producing wheat in the Sudan do not follow a standard system. They include; chiseling, disc ploughing, harrowing, rotovator tilling, and ridging. Common sowing methods are ridge seeding or flat (broadcasting or in lines) sowing.

Farah (1995) reported that 10000 m³ of water per hectare (4000 m³/fed.) are needed to produce optimum grain yield. But, however, saving of water without harming wheat yield and quality can be achieved, and that varietal response differences of wheat to irrigation regimes exist to fill yield gaps. On the other hand, this volume applied regularly under any tillage practice, not based on type of crop and its state of growth, or any particular criteria may not satisfy actual crop requirements. Moreover, to increase productivity and WUE, farmers should be aware of the ill effects of over-irrigation and that, energy is more expensive, particularly in tillage operations and should be efficiently allocated.

It is evident that, the optimum and economical package of tillage and irrigation regime for wheat production need to be identified and related factors to be quantified accordingly and processed. Therefore, the objectives of this study were:-

i- To investigate the effect of tillage practices, irrigation water amount, sowing method, and their interactions on growth and yield of wheat.
ii- To assess the performance parameters of tillage machines based on fuel consumption, workrate, as well as draft and power requirements.

iii- To identify the optimum combination of the experimental factors for wheat production in Shambat area.
2.1 Introduction

Plants require an environment in which nutrients, water and air are available for development, growth and reproduction. These three items are naturally arranged in a specific form (structure), which enables plants to benefit from them. Unless soil temperature is a restrictive factor (in the tropics), the only determinant factor to seed germination is primarily water. If the previous conditions are well reserved, there is no reason for any soil manipulation (tillage). However, if the balance of the ecosystem or natural environment of plant species in a given location is disturbed, e.g. by introducing a predominant crop, then all its cultural requirements should be secured.

Michael (1978) and Perrier and Salkini (1987) stated that, the mode and intensity of tillage depends on the type of soil and related constraints to crop production, to avoid topsoil degradation and subsequent erosion, as well as to fulfil soil conditions favourable for water infiltration, and seedling and root development which ultimately results in economic yield.

Water for crop production is generally obtained from one of three resources; rainfall, surface irrigation supplies, and ground water. However, FAO (2003) reported that, of the 3% of the global resources that is fresh water, liquid fresh water contributes about 1%, almost as ground water, while < 2% of it is to be found in rivers and lakes. Moreover, agriculture remains to be the principle user of all water resources taken together and accounts for about 70% of total withdrawals worldwide, followed by industry (21%). In irrigated
agriculture, about half of water withdrawn is consumed in evapotranspiration for producing 40% of the world’s food on only 20% of the available land.

Water supplies are usually intermittent compared to the continuous demands of crop, which are basically depending on climate, crop, soil and cultural practices. Irrigation is generally resorted to when climatic patterns affect agriculture. Total rainfall may be inadequate or unreliable, technical, socio-economic factors may also justify irrigation. Therefore, Michael (1978) reported that irrigation should be defined in terms of purpose of crop production rather than the mere application of water to the soil surface, subsurface, or aerealy depending on type of soil, water supply and topography of land. Doorenbos and Kassam (1986) stated that whenever water is not scarce, surface irrigation, which comprises furrow, border and basin systems, is the most common practice if proper land preparation for efficient distribution of water with aid of gravity is guaranteed.

Randal et al. (1986) and FAO (1995) reported that 11% of the earth’s land is currently cultivated to produce 97% of our food, where only about 15% of it is under irrigation. Moreover, 66% of the cropped land is used for cereals, with wheat (*Triticum* sp.) ranking the top.

### 2.2 Concept and importance of tillage

Soil tillage has been exclusively defined as the mechanical manipulation of soil using predefined machines to satisfy predetermined objectives. FAO, (1995) stated that tillage includes all operations leading to seedbed preparation that optimizes both soil and environmental conditions for good seed germination, seedling
establishment, and crop growth. However, Lorenz et al. (1984) mentioned that, from a physical side of view, tillage is exerting a pressure on soil system, which differs in magnitude and direction. The soil tends to react differently to that pressure through compaction, deformation, cutting crumbling, pulverization, or transportation. Moreover, for along time, tillage has been practiced with its direct objectives still controversial and merit some discussion. However, Hussein and Munir (1986); Igbeka (1986) and Sharma and Dhiman (1986) stated that although, for long ago, tillage was described as the most costy, time and energy consuming item in the budget of farmer, but benefits obtained from subsistence farming should not be weighed in terms of costs and returns.

Meyer et al. (1989) stated that research is needed to expand knowledge concerning soil and water processes and their interaction as a basis for better management of these resources. Doorenbos and Pruitt (1977) and Yusuf et al. (1998) reported that agricultural mechanization has been receiving considerable interest in recent times due mainly to increasing population and in turn increasing food demands. It does not necessarily mean tractorization, however it is a field in which physical and biological sciences are perfectly blended and utilized for producing, handling, processing and storing food, fibre and fodder. It should be introduced with respect to prevailing environmental, human and social constraint.

Stevens (1994) reported that, three major factors that influence crop production are soil conditions, climate (moisture in particular), and management. However, because tillage influences yields only indirectly, it is difficult to improve yields by tilling the soil in different (improved) ways as it alters both soil conditions and affect farm management
requirements. FAO (1995) concluded that tillage requirements are generally soil and crop specific, and hence climate is a tightly relevant variable. It is however difficult to predict effects of tillage on soils as its physical, biological and chemical characteristics will be affected by the manipulation process. In contrast to temperate regions, tillage practices in arid and semi-arid climates should aim to increase water intake and conservation capacities of soils, reduce evaporation and decomposition rate of organic matter as well as decreasing erosion and control weeds. Lorenz et al. (1984), and Mahmoud et al. (1990) agreed with the previous statement but, described it as a difficult task when we consider effect of tillage on long-term hydrological components (water infiltration, storage, and runoff), as well as geometry of particles and pore space i.e. soil structure. The latter is described by FAO (1995) as the least understood of physical characteristics affecting crop production and tillage requirements, as it is hard to study or assess directly. It involves size, shape, and arrangement of solids and continuous voids, and forces relevant to physical soil characteristics. Structural stability is usually assessed in terms of different properties including total porosity, pore size distribution, available water content, and bulk density.

2.3 Tillage systems

Different systems were known depending on prevailing environmental conditions (climatic regions), in addition to objectives, type and characteristics of soil, as well as availability of machinery. They are, however classified with respect to the sequence of operations, or implements used, seedbed characteristics and requirements. A tillage system may comprise a single pass or more, with one machine, or machines in sequence, depending on crop, state of previous residue or
weeds, soil characteristics, water quality and socio-economic factors. However, the fewer the number of tillage operations needed to create the required soil or seedbed conditions, the better.

FAO (1990) and FAO (1995) stated that, according to tillage intensity and mode, systems are classified into conventional, conservational, and no-till. The former refers to common local tillage practices for a given crop or farming system, and differs with region, continent, country, state and even farm. Conservation systems comprise varying degrees of soil disturbance described as minimum, reduced, low, and finally zero-till.

Tillage systems were also categorized into traditional plough-till (clean-till), and conservational. The former trend implies manual or animal aided slashing of weeds and residues throughout the whole field, burned, buried or left as mulch. Plough-till is the mechanical manipulation of field, mostly through two tillage operations in succession, viz. primary and secondary, with implements drawn by animals, tractors, or other mechanically powered devices. Conventional tillage is synonymous with maximum tillage, clean-till and plough-till. No-till refers to direct seeding. However, a tillage method used to achieve anyone objective may produce a conflict with other objectives, and also with other practices within the whole farming system. For instance, conventional tillage in dry lands of the tropics control weeds and decrease evaporation by mulching, but it might increase the risk of soil erosion when maximum tillage intensity and continuity is adopted. Moreover, there is a great tendency of farmers to use tillage implements in the vicinity, or the prevailing methods that are generally accepted by others, which represent a common problem in many arable lands.
However, tillage practices in general have not changed much since the early 20th century (Doorenbos and Pruitt, 1977; FAO, 1995).

Alternation between conventional tillage and conservation tillage, introduction, and prolonged practice of either of the two systems, have detrimental effects on crop growth in some soils as different practices affect structural stability, residue condition, biological activity and later influence water infiltration, aeration, and organic matter status. Many researchers agreed that, although tillage loosens the soil, but this effect will last shortly and more compaction of soil layers will ultimately be incurred. Restoring or maintaining a good soil structure under minimal, or no-till, on the other hand, can take place only if the organic matter in the soil increases considerably, and macropores continuity is guaranteed, mostly due to sustained mulch.

Bukhari et al. (1992) concluded that, qualities of good seedbed constitute equal loosening, sufficient crumbling and controlled leveling. However, when soil inversion is required, the furrow slice should be perfectly dealt with to enhance weed decomposition and prevent its regrowth.

2.4 Implements for soil tillage

A wide range of implements was available under a wide range of conditions, before, during, and after the vegetative period of the crop. They suit various soils, climates, and socio-economic conditions. Lorenz et al. (1984) Stated that, different criteria should be considered when selecting a tillage implement for a given tillage system. Beside being trouble-free regarding the entire sequence of implements and operations, the potential side-effects such as; soil compaction, erosion, weed control, decomposition of organic matter, conservation or loss of soil
water, salinization, should be carefully considered. Machine compatibility, accessibility, and time operation should not be ignored.

Tillage implements are widely divided into two categories viz. primary and secondary tillage implements.

2.4.1 Primary tillage implements

To create pore volume for absorbing water and air, to allow easy penetration of plant roots by loosening the soil downwards, inversion of soil to bring up leached fine soil materials and nutrients to the surface, deposition of organic matter into deeper layers, control of primary weeds, and breaking hard pans, are major objectives of primary tillage. Crumbling and mixing of soil material is possible if succeeding tillage operations are to be reduced or omitted.

A typical concept of primary tillage in the tropics and subtropics dry farming, is to loosen the soil without inverting it, leaving a rough structure without completely burying residue to alleviate erosion risks.

Four main types of implements are popularly accepted and used as primary tillage implements; namely moldboard, disc, chisel, and subsoiler, ploughs. Each of which has its specific features.

Moldboard is the common implement of the temperate regions. Subsoilers are implements having a very specific and specialized function; viz. deep ploughing for breaking hard pans of up to 100 cm soil depth even in a very compacted hard clayey soil. It loosens soils below the normal depth of tillage for maximum retention of water, and root development (Hussein and Munir, 1986).

2.4.1.1 Disc plough (conventional 3-bottomed)

Disc plough is the most common primary implement in regions other than the temperates, to fraction a portion of the profile, partially or
completely inverting and mixing soil horizons, as well as to bury weeds at a range of depths of 30-46 cm (Hussein and Munir, 1986). It works best on sticky, waxy, hard dry, rough stony, and rooty ground soils. It has considerable pulverizing and lifting ability of soil, and of a medium water retaining effect. Lorenz et al. (1984) concluded that, this type of plough is suitable in soils that are not too moist, and when erosion risks are greater. Shirin et al. (1993) reported that, disc plough consumes much energy, and has greater draft requirements which increases with increased speed and clay content. Degree of soil inversion tends to be reduced with increased tilt angle, and that disc penetration was best at a low tilt angle. Reduced penetration has the advantage of reduced draft requirements. Hussein and Munir (1986) reported an effective ploughing depth of 10-15 cm, also Yusuf and Asota (1998) reported 16 cm.

2.4.1.2 Chisel plough

Chisel plough is a sort of ploughs that has a maximum loosening effect on soil, but with minimum pulverizing, mixing, and inverting effects. It has a workable depth range of 46-76 cm, and generally suits all types of soils, especially light ones that are free of stones and similar obstructing objects. It has a maximum water retaining effect. Commonly used to establish an initial attack to loosen hard dry soils before subsurface or secondary tillage practices. It can be safely and effectively used to break up hard pans just below regular plough depth if heavy subsoilers are not necessary (Doorenbos and Pruitt, 1977).

2.4.2 Secondary tillage implements

Secondary tillage operations are optional complementary measures that mostly follow a primary tillage operation. Sometimes secondary operations may be considerably reduced or even completely
omitted for economical or conservational justifications, depending on prevailing farming conditions. They include implements that crush, or pulverize clods resulting from primary tillage, leveling and establishing furrows or beds for crop planting.

2.4.2.1 Disc harrows

The most popular of harrow groups. They are very affective clod crushers, and surface smoothing implements. They are of single-acting, offset, or double-acting (tandem) disc harrows.

Hussein and Munir (1986); and Yusuf and Asota (1998) reported workable depth range of 10-15 cm. Abdul Razzaq et al. (1993) stated that disc harrows can easily open soil up to an average depth of 23 cm, and partially inverts it by moving it to the right direction with the front gang, followed by similar action to the left direction with the rear notched blades’ gang. They can effectively be used on soils that are medium hard and with their surfaces covered with stalks, stubble and other debris. They have medium soil inversion abilities. Beside their wide use as clod crushers, they stir soil and cover seeds, green manure, and weeds.

Offset disc harrow is the most commonly used among harrows in both irrigated and rainfed agriculture. Deviations from the designed surface in irrigated farming can effectively be avoided by offsets. They are either of light or heavy duty types according to draft requirements which ranges between 375-600 kg (force)/width of cut (Barnes, 1971 and Hussein and Munir, 1986). Under gravity irrigation in general, water control becomes a dominant factor in the selection of land preparation as to maintain the design surface and to establish the desired micro-topography.
2.4.2.2 Ridgers

Stevens (1994) stated that, ridging results in better soil and water management in surface irrigation than just establishing a seedbed. It determines the slope along which water can runoff, and may further decrease that slope to safer ranges when non-erosive speeds of water flow are required. Lorenz et al. (1984) recommended ridging for water and temperature control, furrow irrigation, erosion control, as well as for improving harvesting methods.

A ridger consists of ridging bodies (3-5), with adjustable spacing. Ridges that are of 70-80 cm spacing are commonly used. They are becoming reliable primary tillage tools in irrigated farming (Yusuf and Asota, 1998) particularly in furrow irrigation.

Leveling is one of the key operations with respect to gravity irrigation. Levelers of wide ranges of complexity in design are commonly used. However, the traditional and locally made versions depend on operator skill and more time is needed to work a confined area.

Pandey and Pal (1973) stated that as far as surface irrigation is concerned, uniform and efficient water distribution in the field, eliminated probability of water wastage, and good leveling and levelers would ensure uniform crop growth.

Khattab et al. (1982) reported 17, 39, and 67% savings in number, period, and cost of labour, as well as 32% savings in wheat yields were obtained after leveling, compared to non-leveling, surface-irrigated field. On the other hand Carruthers and Clark (1983) stated that, in furrow irrigation, 75% of capital cost may go for leveling in areas with labour scarcity, or with high opportunity cost, uneven land, but with no limitation in capital.
Lorenz et al. (1984) suggested a complete ideal land preparation system which comprises post-harvest tillage to restore soil structure, main tillage, secondary tillage to establish the final seedbed, and crop management tillage for weed control, break up of surface crust, and to increase infiltration. Hussein and Munir (1986) on the other hand, categorized implements with respect to soil type and prevailing climatic conditions. They recommended disc ploughs followed by disc harrows for stony and clayey soils. For sandy and loamy soils, disc harrows after chisels are the best choice. Dawelbeit (1995) reported many plough systems for producing wheat in the Sudan, which comprises twice harrowing, harrowing after disc plough (3-bottomed) or ridger and ridging twice, followed by leveling. He stated that primary tillage is usually practiced to alleviate compaction from the heavy cracking vertisols. Erbach et al. (1992) generalized that, effective tillage system is that trend which creates soil conditions favourable for infiltration, seed germination, plant emergence and growth, root development, and permits erosion control.

### 2.5 Effect of tillage on seedbed characteristics

On-farm cultural practices are a complex blend of art and science, such that the best knowledge of soil, crop, climate and water; together with other relevant inputs should be applied for an economical and sustainable agricultural production (Maurya, 1989; and FAO, 1995).

Abdul Razzaq et al. (1993) reported that, optimization of physical inputs through appropriate bio-hydro-chemical technologies is a prerequisite for obtaining maximum crop yield. However, optimum tillage is the key element for the effective application of these inputs to maintain plant nutrition and healthy growth. Nevertheless, tillage can
never be evaluated in isolation, as subsequent operations such as seeding, irrigation, and harvesting should inevitably be influenced.

Dawelbeit (1995); FAO (1995); and Kumar (2000) reported that, soils of the semi-arid tropics, are predominantly vertisols that are characterized by impeded trafficability when wet, and cracky when dry, which makes their mechanical manipulation difficult. These soils are potentially productive, prone to erosion and structural degradation under faulty tillage. Aeration, water movement, infiltration of water will be restricted.

Hajabbasi (2001) reported that in arid, loamy mixed soils with weak structure, with low organic matter, tillage operations improved root morphological characteristics. However, Lonita et al. (1999) stated that, when energy, time and impact on soil are to be reduced the working depth, intensity and action of tillage should be kept at the minimum level. This statement was confirmed by Mahey et al. (2002) from their no-till trials with spring wheat.

Bukhari et al. (1992); Yassen et al. (1992) and Chi et al. (1993) mentioned that tillage affect seedbed either positively or negatively. It loosens, crumbles, aerates and warm it (improved structure) and favours availability of soil moisture and nutrients. The negative effect on the other hand is incurred directly through soil compaction resulting from heavy machinery and equipments’ maneuverability. About 90% of soil surface can be traversed by tractor wheels during primary tillage that significantly inhibits pore continuity to sustain root development and water movement. Williams (1986) reported that 90% of total compaction occurs during the first pass.

Maurya (1989) stated that, in semi-arid tropics, tillage is a prerequisite to release soil compaction and the relatively higher bulk
density, low porosity, reduced infiltration, and low water holding capacity, as crops raised under such conditions without tillage, are usually stunted due to lack of nutrition and moisture. Nasr and Selles (1995) supported this statement as crops are basically affected, in terms of emergence percent and speed, by bulk density and aggregate size of seedbed, and their interaction. Increased bulk density or aggregate size tends to delay and reduce emergence by reducing volume of voids. However, effect of bulk density was small in seedbeds with large aggregates, and the effect of aggregate size was negligible in compacted seedbeds. Erbach et al. (1992) reported similar results.

2.5.1 Effect of tillage on soil physical properties

Michael (1978); Perrier and Salkini (1987); Chi et al. (1993); FAO (1995); and Khan et al. (2001) stated that soil physical properties such as infiltration and moisture storage capacities, bulk density, soil strength and pressibility (compaction), porosity and aggregation, sealing, and crusting, were commonly assessed and evaluated to detect the influence of different tillage practices on soils.

Kay et al. (2002) reported that changes in tillage practices lead to changes in pore characteristics with space and time. The rates of changes are crucially vital to interpreting the short and long-term impacts of tillage on productivity and hydrology of arable soils. Similar statements were reported by Erbach et al. (1992) when they detected recompaction with time after planting to about the same initial density as before tillage, due to natural processes and/or subsequent machinery travel.

FAO (1995) highlighted the significant contribution to declining productivity arising from loss of inter- and intra-aggregate voids
resulting from collapsed soil structures. Crusted and sealed soil surfaces reduces infiltration through blocked uppermost pores resulting from faulty tillage preceding irrigation or raindrop impact. The final result is root aeration impedance and water logging.

**2.5.2 Effect of tillage on infiltration**

Michael (1978) and Perrier and Salkini (1987) defined infiltration as the vertical, one-dimensional flow of water into the soil. The rate of infiltration is higher at the start of irrigation and tends to decrease with time till it reached a constant value (basic infiltration rate). The amount of water entered the soil profile at a given period of time (t) is the accumulated infiltration ($\gamma$). This relation is empirically expressed.

$$\gamma = at^\alpha \quad \text{or} \quad \gamma = at^\alpha + b$$

Where:
- $\gamma =$ accumulated or cumulative infiltration, cm
- $t =$ elapsed time(t) or infiltration opportunity time for the amount ($\gamma$) to infiltrate, min.
- $\alpha,$ a and b; characteristic constants ranging 0-1

Hillel (1971) and Sakai *et al.* (1987) stated that, infiltration in terms of water supply is either flux-controlled or profile-controlled. In contrast to the latter, the former state arises when water applied to the soil surface is smaller than the soil infiltrability and water tend to infiltrate as faster as it is supplied. Khan *et al.* (2001) described infiltration as a hydro-physical characteristic of soil that was commonly
determined to assess the comparative effects of different management techniques on plough zones or deeper soils.

Various factors were reported by many researchers as affecting infiltration rate. Michael (1978); Kooistra et al. (1984); Unger (1986); Perrier and Salkini (1987); Meek et al. (1990); Erbach et al. (1992); Meek et al. (1992); Christensen et al. (1994) and Ankeny et al. (1995) mentioned many factors including initial moisture content, bulk density, soil texture, porosity and aggregation, conditions of soil surface (including roughness, slope, vegetation, sealing and crusting), restrictive layers below soil surface (compaction), swelling-shrinkage ability of soil, hydraulic conductivity of soil profile, state of macropores, duration of irrigation and runoff, and viscosity of water to be affected mostly, directly or indirectly at varying degrees. However, many of them described the effect of tillage on infiltration as being confusing and contradictory, depending on the degree of compaction, and crushing of plough pans for macropore continuity. Davidoff and Selim (1986); Van Es et al. (1991); Duke (1992) and Sakai et al. (1987) reported that infiltration process is affected by spatially variable physical conditions of the soil near the surface and the vertical soil matric-potential gradient at the onset of that process, which resulted mainly from tillage and irrigation.

Michael (1978); Packer et al. (1984); Meek et al. (1992) and Ankeny et al. (1995) stated that the improvement of hydraulic characteristics of soils as due to increased porosity and decreased bulk density resulting from tillage, were temporary and will last soon after the first irrigation when the recently tilled soil particles settle back to its former conditions of bulk density, and thus block water pores. Similar observations were stated by Azevedo et al. (1998) when they report 70-
80% of infiltration in cultivated land through macropore flow at soil surface which tend to decrease with depth and time. On the other hand, the fact that infiltration was fairly correlated \((r^2 = 0.60)\) with bulk density in plough-till and extensive tillage (annual cropping) was reported by Potter et al. (1988); Meek et al. (1989) and Meek et al. (1992). But, however, they did not report any correlation \((r^2 = 0.007)\) of infiltration with bulk density under no-till and minimum-till conditions as it depends mainly on natural and biological channels continuity which affected by compaction. Such findings were observed when infiltration increased in undisturbed, non-trafficked clay loam, but decreased when the same non-trafficked soil was tilled. They concluded that, when infiltration is to be improved by altering bulk density values, tillage should be restricted only to compacted soils. However, Edwards et al. (1988); Meek et al. (1989); Meek et al. (1990) and Mahboubi et al. (1993) pointed out that it is the longevity component that should be considered in macropore system since macropores, as well as root development and effect, need time. Therefore, systematic and comprehensive analysis from long-term experiments is needed. Macropore system effect can be witnessed at least with prennial cropping system than annual or fallow systems. However, no-till or minimum-till systems preserve macropore flow system from one crop to the next. Both Culley et al. (1989) and Mark et al. (1990) confirmed similar observations that macropores of tilled trafficked soils were compacted and resulted in more poor drain soils. They also reported that soil samples with many roots should have lower bulk densities and higher infiltration, otherwise root might have filled macropores.
Radcliffe et al. (1988) reported infiltration rates of 37.0 and 16.0 mm/h for no-tilled and plough-tilled plots, respectively but basic infiltration rates were similar (1 mm/h) when crop residues were removed from no-tilled plots. They concluded that it is the significant effect of cover rather than tillage systems. Daniel et al. (1992) reported similar conclusions in clay looms.

Ray and Gupta (2001) found that both disc plough and chisel decreased bulk density but increased saturation percent and amount of macropores > 0.30 mm when used for wheat seedbed. The final infiltration rates were two-fold higher for both, and 33% higher under the disc harrow treatments, than no-till treatments.

Meek et al. (1992) stated that infiltration rate of a tilled sandy loam soil tend to increase due to decreased bulk density. However, for an untilled-cropped sample, it can be improved with time, as channels will be developed. In contrast, Acevedo et al. (1990); Harris et al. (1991); and Erbach et al. (1992) stated that for fine-textured soils of arid and semi-arid regions, where water is limited and evaporation values exceeds 50% ET\textsubscript{crop}, infiltration might be improved by clean-till for roots to extract more available water from subsurface layers, and by reducing evaporation.

The generalization that, lower infiltration rates near soil surface of no-tilled systems compared to plough-till systems was reported by Lindstrom (1988); and Heard et al. (1988). Perrier and Salkini (1987), and Bukhari et al. (1992) reported that, in the tropics and subtropics infiltration and crop yield can be improved, and risks of crop failure can be alleviated by some tillage techniques such as deep ploughing (30 - 40 cm), Chiselling (30 cm), surface tillage (minimum) for removing surface crust and managing vegetative cover.
Allen and Musick (1997) observed increased water infiltration from the first irrigation by up to 28% by increased tillage due to chiselling (15 - 28 cm), but its effect on succeeding irrigation severely declined (20% less), 60 days after. However, they did not report any significant differences on this respect, to be due to tillage method or depth.

Moreno et al. (1997) reported 35% higher infiltration rate for disc plough-harrowed system, than chisel-based system on the same type of soil. Sabir et al. (1996) reported maximum infiltration rate in disc ploughed plots (20.57 mm/h) compared to chiseled and reduced- tillage plots. They attributed this to deeper soil disturbance, as well as increased gypsum that improved infiltration in saline soils.

Ankeny et al. (1995) did not observe significant differences in infiltration between chisel-based and no-till treatments in a trafficked sandy clay loam despite the fact that chisel plough created much pores for water infiltration, which resulted in numerically higher values of infiltration rates. But, these voids might have been blocked with time when soil particles consolidate and settle. However, for trafficked soils, chisel-based system had significantly greater infiltration values than no-till systems.

Erbach et al. (1992) reported that chisels tend to reduce both bulk density and penetration rates slightly compared to no-till. It loosens soil with minimal residue disturbance that results in great benefits for root development and improved infiltration. Hamblin (1984) pointed out similar observations when he reported higher moisture contents at 0 - 50 cm soil depth of unploughed soil when compared to chiselled soil of similar texture.
2.5.3 Effect of tillage on bulk density

Chi et al. (1993) reported that bulk density (b.d) often measured to evaluate the effectiveness of tillage operation. It often varies between 0.9 - 1.8 g/cm³ for agricultural soils. It is not affected by arrangement of soil particles or by the size distribution of soil pores.

Raines and Bicki (1993); Hill(1987); Kumar and Pandey (2000); and Sabir and Mrabet (2002) reported maximum bulk density and soil strength in the upper 30 cm in no-tilled plots than deep tilled ones. But however, they did not detect uniform effect of plough-till on bulk density or pore size distribution.

Oni (1991) and Maurya (1993) reported increased bulk density values with disturbed soil depth up to 10 cm, and that bulk density was significantly influenced by tillage outcomings, particularly compaction. Moreover, soil strength tends to increase with depth of soil.

Ahmed and Haffar (1993) reported no significant variations in seedbed bulk density in the upper 10 cm between heavy duty disc harrow, subsoiler, chisel plough, disc plough and light disc harrow (1.04, 1.15, 1.03, 1.15 and 1.18 g/cm³, respectively). However, significant differences in soil bulk density below this layer with chisel and subsoiler, resulting in less dense soil at 20 - 30 cm depth (1.33 and 1.24 g/cm³, respectively), compared to 1.55, 1.46 and 1.57 g/cm³ for the remaining implements, respectively.
Sabir et al. (1996) reported that hard pans of up to 60 cm soil depth can be effectively dealt with by chiselling. He ended up with bulk densities of 1.80 and 1.40 g/cm³ at 15 - 30 and 45 - 60 cm depth, respectively, compared to disc plough and subsoiler. However, when soil cohesion is to be reduced, disc plough was proved to be the best. Infiltration rates of 2.0 - 5.7 cm/h were described as being better with disc ploughing. Generally, deep ploughing is oftenly accompanied by better infiltration rates, at least during early events due mainly to improved bulk density.

Hamblin (1984) found that bulk density resulted from disc plough was lower compared to chiselling in a clay and loamy clay soils. Chisel has significantly lower bulk density at 10 - 15 cm soil depth in a wide range of soils. Abdul Razzaq and Sabir (1992) reported similar observations. Moreover, Johnson et al. (1982) stated that although conventional plough-till is always associated with increased moisture losses than no-till or reduced-till, but when chisel plough was included in the system available water infiltration increased significantly, mostly due to increased bulk density of soil surface. Kumar (2000) reported significant reductions in bulk density values with increased number of tillage operations from no-tillage to up to six harrowing, varying from 1.49 - 1.22 g/cm³.

Yassen et al. (1992) reported significant affect on bulk density due to disc ploughing. But, passage of heavy machinery and equipments for succeeding operations recompacted the soil and increased its bulk density directly below 20 cm depth. Also considerable variations in soil moisture content within 0 - 10 cm depth were reported between ploughed and unploughed clay loam soil, most likely to be due to lesser evaporation rates of unploughed soil (no-tilled plots).
Generally, Mahboubi et al. (1993) stated that wheel-induced compaction was the over-riding factor that minimized the effect of tillage methods on bulk density.

For additional elaboration, refer to part 2.5, 2.5.1 and 2.5.2.

### 2.5.4 Tillage and soil compaction

Perrier and Salkini (1987); Chi et al. (1993) and FAO (1995) stated that compaction remains to be the most critical physical criterion that alters a wide range of properties, which are commonly used to locate it such as soil strength. It varies directly with soil density and inversely with soil moisture. Axial load and number of passes of machine are its major causes in arable lands.

Bashford et al. (1991) and Erbach et al. (1992) mentioned that, soil compaction is basically the major constraint to increased yields in tropical soils. It was far more severe in clays than coarse-textured soils. Nasr and Selles (1995) stated that, in soils containing appreciable amounts of coarse-textured particles, controlled compaction tends to increase bulk density, break down larger aggregates and increases infiltration and storage capacity of water. Erbach et al. (1992) obtained wheat yield increases of 19.6, 25.9 and 25.3% when a sandy soil was treated with 10, 20 and 30 passes with a 200 kg roller, respectively due mainly to improvements in water storage capacity resulting from increased bulk density (1.05 - 1.20 g/cm$^3$). Water savings of up to 15 - 36% were also obtained. Meek et al. (1989) reported increased infiltration rate in sandy loam soil when lightly compacted before the first irrigation. However, Meeks et al. (1992) reported significant decreases in infiltration rate when the same soil was compacted at field capacity than air dry compacted.
Chaudhry (1985) and Sabir et al. (1996) stated that, hard pans are partly due to inherent soil composition or resulting from tillage practices. Plough pans can be easily smashed by chiselling if salt hazards are probable with subsoiling. Clay pans underlying sandy or sandy-loam soils that are shallow (20 - 26 cm).

Bicki and Siemens (1991) and Voohees (1983) stated that, releasing or restoring soil compaction, depending on prevailing climatic and edaphic conditions would generally improve soil water storage capacity and increase crop productivity.

2.6 Machine performance

2.6.1 Traction, travel reduction (slippage), and energy consumption

Ademosun (1991) reported that, tractor, man, and draft animals are the major power sources of farm implements and tools, and it is not possible to perform crop production processes without them. Draft animals are restricted and will not permit subsoil nutrients and moisture to be fully exploited, and sub-soil hard pans to be broken. Tractors and man are required everywhere, and the latter is still needed at least to operate the tractor. Kumar and Ahmed (1996) considered tractor as the most important item of farm investment after land. Its efficient use increases inputs productivity, and in turn increases production.

Pudjiono and MacMillan (1995) and Ozanslan and Erdogan (1996) stated that, under ideal field conditions, data of tractor’s power take-off (PTO) power, forward speed, and traction reduction can be efficiently used to predict tractor performance in terms of its drawbar pull, horsepower, travel speed and travel reduction under various field and machinery conditions.
Hussein (1988) reported that, the energy consumption per unit of output is less in growing rainfed (extensive) crops than irrigated (intensive) crops due to differences in cropping pattern.

According to Kepner et al. (1978), power requirements for mounted tillage implements, including disc plough, chisel, ridger and disc harrows is the drawbar power that is actually required to pull or move the implement at a uniform speed.

Shebi et al. (1988); Shinners and Wehler(1992); and Baloch et al. (1993) defined traction as the force applied to the tool which causes the elements to move through the soil. A traction device (tyre) converts rotary motion derived from the engine into useful linear motion (pull). However, because some energy is required for tractor parts to run itself, and less efficient energy transmission, tractor and implement weights (drawbar loads) are still required as efficient traction requirements, and sufficient power to overcome rolling resistance and slippage.

Saleque and Jangiev (1990) and Pudjiono and MacMillan (1995) stated that, reduction in energy waste in tillage operations depends upon the matching of tractor-implement and their operating characteristics and this can be adjusted only by experimentation.

Srivastava (1982); Wali Ullah and Kofoed (1987); and Shebi et al. (1988) mentioned that energy consumption depends on many factors including, soil type and strength, tilling depth, forward speed and quality of tillage. Bashford et al. (1991) recommended that disc ploughs and heavy duty offset disc harrows have higher energy requirements, and should not be used when other less aggressive implements like tandem disc harrows and cultivators are available. Similar observations were reported by Shirin et al. (1993). Poje (1996) mentioned similar literature about disc plough in terms of its power, and energy/unit area.
requirements. However, he added that, the per area energy requirements of chisel and offset disc harrow were comparatively smaller owing to their larger work rate or effective width. He reported 44% more power requirements of disc plough and chisel compared to offset.

Finney (1982); Kepner et al. (1982); Bukhari et al. (1988); and Bashford et al. (1991) stated that draft requirements of machines varied according to machine and tyre types, soils, field conditions, tractor characteristics, depth and speed of work, and the interaction between these factors. Singh and Rautaray (1982) and Mckyes and Maswaure (1997) reported that, traction increases with increased soil compaction, bulldozing resistance, optimum soil contact area of wheel, increased depth and width of tool, and angle of attack.

Igbal et al. (1994) reported that, draught requirements of chisel plough tend to increase linearly with depth of tillage. Disc harrows have curvilinear relationship. Maximum power consumption was recorded by chisel plough, which amounts to 40% of the effective power from a 35.43 kW tractor in a clay soil.

Dahab and Mohamed (2002) reported higher tractive force (11.5 kN) and traction power (17.3 kW) for chisel plough than disc plough on a moist heavy clay soil with reduced tyre pressure (25 psi). They recorded significant differences in traction performance between the tested implements due to soil moisture content, and tyre inflation pressure.

Ahmed and Haffar (1993) attributed the attainable differences in fuel consumption (l/ha) in the following descending order; heavy duty offset disc harrow, disc plough, chisel plough, and light offset disc harrow, to draft and traction requirements of the same order; and work rate (ha/h) which appear in an ascending order. Riethmuller (1989)
stated that, all the tested implements for draft requirements showed linear increase in draft with depth and speed. Disc plough had the lowest draught and the lowest increase in draught with speed on a sandy loam (14% clay), and a higher draught on a sandy clay loam (29%).

Singh et al. (1981) stated that, when all other parameters are kept ideally constant except for speed, unit draft increased curvilinearly for offset disc harrow, being 0.115 and 0.348 kg/cm$^2$ at 0.868 and 2.25 m/sec, respectively. Similar observations were reported by Finney (1982) who further added that, traction effort and penetration of offset disc harrow would be improved by adding weights, using smaller diameter discs or wider spaced discs. Bashford et al. (1991) reported greater unit draft requirements for disc plough, followed by heavy-duty offset, and finally chisel. Lando (1989) highlighted the role of soil moisture in altering power requirements of implements, as well as ploughing depth. Maximum draught requirements were reported at 30% moisture content (d.b), and 20 cm depth for a disc plough at a constant ploughing speed of 5.40 km/h, and 20 cm ploughing width. Panigrahi et al. (1990) reported that, depth of penetration of disc plough tend to decrease with the increase in soil moisture content. Maximum depth of cut was reported at 9.3, 8.3, and 9.2% soil moisture content in clay loam, sandy, and sandy loam soils, respectively. Tranggono and Willatt (1989) generalized that, draft force was lower for loamy soils (22% clay) than in clays (75% clay). Shirin et al. (1993) reported a linear increase in specific draft (kN/cm$^2$) requirements of disc plough with increasing ploughing speed (1.34 - 2.68 m/sec), being 40% and 90% for clay loam and fine loam soils, respectively. They observed a significant decrease in draft with increased moisture content from 23.3 to 33.4% (d.b). Moreover, Patterson (1982) stated that, draught implements
particularly disc plough and chisel perform well in dry than wet soils due to reduced slippage. Bandy et al. (1986) recorded up to 27% saving in power for chisel plough when compared to moldboard and disc plough under comparable field conditions.

Burt and Lyne (1985) did not find any measurable forward speed effects on net traction requirements of disc plough or ridger on a sandy clay soil over a range of 0.1 - 0.6 m/sec of forward velocity. Shirin et al. (1993) attributed the increased total draft with ploughing speed to the obstruction in easy flow of soil at the R.H.S of discs at high disc angles of disc plough.

Laurel (1988) reported that, excessive travel reduction of tractor is a common problem in developing countries, as well as fuel waste. It hastens tyre wear and compaction, particularly in light and wet soils. He recorded up to 12 to 15% slip as a measurable maximum level irrespective of machine used. Shebi et al. (1988) found that, travel reduction tend to be reduced with increased speed which resulted in increased drawbar power. This was attributed to less time being available for implement to penetrate into the soil. Decreased contact area between soil surface and traction device (wheel) tends to significantly increase slippage, and hence reduces drawbar power. Pensson et al. (1986) indicated a top limit to travel reduction of about 25% under maximum loading and depth when working on a heavy clay soil.

2.6.2 Fuel consumption

Wali Ullah and Kofoed (1987) stated that, among major tractor costs, fuel is the leading item as direct expense on farmer budget. Bowers (1986) stated that maximum productivity with minimum usable
fossil fuel should be the challenge of today’s tasks of reduced inputs. Pensson et al. (1986) added that, two limiting factors of tractor performance optimization are fuel consumption and field capacity. It is usually expressed as specific consumption (l/kWh), or per hour consumption (l/h).

Bukhari et al. (1989) mentioned that oil and fuel consumption varies according to tractor size. Sommerburg (1986) indicated that adjustment of working width is key element for matching implement to a given tractor for minimum fuel consumption. Shebi et al. (1988) stated that, fuel consumption depends on tractor annual use, age, and labour costs for maintenance. Smith (1993) indicated 45 - 60% of consumed fuel to be required for the tractor to propel itself.

Bowers et al. (1989); Michael et al. (1983); Robinson and Wentzel (1983); Bandy et al. (1986); and Hernaz et al. (1995) stated the fact that conservation tillage consumed less fuel, time and labour for producing food crops compared to plough-till systems. Up to 43% fuel savings were reported for chiselling as a minimum tillage tool. Bowers (1989) observed the following descending order for fuel consumption (l/ha); disc plough, chisel, and offset disc harrow. Bukhari and Baloch (1982) and Bowers (1989) reported similar findings. The latter researcher found fuel consumption of up to 20.88 and 28.36 l/ha for chisel system in a sandy clay loam and loamy sand, respectively.

Ahmed and Haffar (1993) reported significant variations between offset disc harrow, disc plough and chisel in terms of their fuel consumption and work rate on a heavy clay soil in Sudan. The per hectare fuel consumption was 10.6, 10.0, 9.4 and 8.2 for heavy duty disc harrow, disc plough, chisel, and light offset disc harrow, respectively. Differences in fuel consumption were attributed mainly to draft
characteristics and depth of work. However, the per hour consumption was as follows; heavy-duty disc harrow (19.5 l); Chisel plough (13.6 l); and disc plough and light offset disc harrow (7.1 and 7.5 l, respectively). They attributed this grouping to the corresponding effect of their respective field capacities.

Igbeka (1986) stated that major variables of direct influence on fuel consumption for any operation are speed, soil properties and operator skill. He reported the highest ploughing costs, in terms of fuel, lubricant, labour, and total costs to be for disc plough than ridger and disc harrow, in Nigeria. In the Sudan, fuel cost contribution to total cost was reported by Ahmed and Haffar (1993) to be 42, 49 and 46% for light offset, heavy duty offset, and chisel plough, respectively.

2.6.3 Field capacity and operation efficiency

Pensson et al. (1986) stated that, the optimum field operating speed for tillage that guarantee optimum operation capacity and efficiency was related to proper power unit and machine operating width. Increased depth and traction resistance has significantly reduced field capacity and fuel consumption.

Igbeka (1986) obtained the lowest field capacity and efficiency with disc plough, followed by offset disc harrow and finally ridger on a heavy clay soil. He attributed these findings to the smaller effective ploughing width at comparable ploughing speeds. Offset disc harrow has greater work rate, but tillage depth was the lesser.

Hanna et al. (1979) and Wali Ullah and Kofoed (1987) mentioned the effect of total time used to perform an operation on machine performance. Time losses resulting from discrepancies in time operation
due to field size, theoretical capacity limitations, machine maneuverability, and operator skill, should be carefully considered.

Saleque and Jangiev (1990) stated that, the significance of ploughing speed can be realized only when the area (A) tilled/unit energy is maximized, i.e.

\[
A = \frac{C}{Ne} = \frac{W \cdot V}{Ne} \rightarrow \text{maximum}
\]

Where:
- \(A\) = area tilled/unit energy (m\(^2\)/j)
- \(C\) = effective field capacity (m\(^2\)/sec)
- \(Ne\) = input (axle) tractor power (W)
- \(W\) = width of tillage implement (m)
- \(V\) = travel speed of tractor (m/sec).

Abdul Razzaq and Sabir (1992) stated that, field efficiency of chisel plough tend to increase with increased soil texture coarseness, but decreases in loose soil state. In contrast, for disc harrow, field efficiency increased in both states of soil (firm and loose) with texture. Disc plough has an increasing field efficiency but at an increasing rate when soil texture becomes coarser.

Ahmed and Haffar (1993) recorded field capacities of 1.84, 1.45, 0.91, and 0.71 ha/h, for heavy-duty offset, chisel plough, light offset, and disc plough. Lesser work rate (ha/h) was recorded for disc plough compared to chisel. Patterson (1982) reported similar findings.
2.7 Effect of tillage on crop water requirements or crop evapotranspiration or consumptive use

2.7.1 Concept and importance

Doorenbos and Pruitt (1977); Michael (1978); Doorenbos and Kassam (1986) and Doorenbos and Pruitt (1998) use CWR, ET_c, ET_{crop}, C_w and U synonymously to identify the depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil, water, and fertility, and achieving full production potential under the given growing environment. It combines both evaporation from underlying surfaces and transpiration from living plants plus an insignificant (< 1%) amount of water actually used by plant for its metabolic activity. It combines both the effect of climate (as reference crop evapotranspiration, ET_o) and crop factors (soil coverage by crop, K_c), as well as other factors concerning local farming and management conditions on crop water requirements. ET_{crop} is expressed in depth of water per time period e.g. mm/day (Doorenbos and Kassam, 1986). It can be measured directly by using lysimeter method, field experimental plots, soil moisture depletion studies and water balance method. Direct evaporation data can also be obtained from a properly located evaporation pan depending on geographical and climatic conditions of the area. ET_{crop} would therefore be calculated by relating pan evaporation (E_p) to crop factor, which expresses foliage and location characteristics, and stage of crop growth. However, due to difficulty in obtaining accurate direct measurements under field conditions (Doorenbos and Pruitt, 1977; Doorenbos and Pruitt, 1998), ET_{crop} has been reliably estimated from climatological data. The most common methods used for this respect are; Blaney-criddle, Thornthwaite,
Christiansen and Penman. However, recently formulae derived originally from these ones (modified formulae) were conveniently used today. They generally express the effect of three major components; climate, crop and local conditions and practices on CWR. The first two components are expressed as reference crop evapotranspiration ($ET_o$), and crop coefficient ($K_c$), respectively which is then combined to express actual crop evapotranspiration ($ET_{crop}$) as follows:

$$ET_{crop} = K_c \cdot ET_o$$

CWR is then calculated when effects of management such as irrigation practices, effects of climate variability over time and area, level of crop production, and water availability, were considered. Finally, total CWR need to be applied is:

$$CWR = \frac{ET_{crop}}{e}$$

Where:

$$e = \text{overall irrigation efficiency comprising mainly conveyance and application efficiencies.}$$

### 2.7.1.1 Reference crop evapotranspiration, $ET_o$

Doorenbos and Pruitt (1977) stated that, $ET_o$ expresses the effect of climate on CWR, and defined it as; “the rate of evapotranspiration from an extensive surface of 8 - 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground, and not short of water”. Doorenbos and Kassam (1986) and FAO (1998) described it as the evaporative demand of air independently of crop type and development, and management practices. In semi-arids and arids of the tropics, it is 4 - 10 mm/day vs. 6 - 10 mm/day in the subtropics. However, Carruther and Clark (1983) stated that, it should be taken as 5
- 8 and 9 - 12 mm/day in humid tropics, and arids, respectively. In the Sudan Gezira, it is 6.5 - 7.5 mm/day taken from August to April.

2.7.1.2 Crop coefficient (Kc)

Doorenbos and Kassam (1986) and FAO (1998) described crop factor as an empirical coefficient relating $ET_o$ to maximum crop evapotranspiration ($ET_m$) when water is presumably fully meets crop requirements. It varies with type and developmental stage of crop, and to some extent wind speed and humidity. For most crops it increases from a low value, oftenly < 0.4 during crop emergence to a maximum value during the period when the crop reaches full development, before it declines at maturity. Standard tables showing $K_c$ values for different crops and at their different developmental stages depending on humidity (RH) and wind speed (U), are usually available. On range basis, they reported $K_c$ values for wheat throughout its life span as; 0.3-0.4, 0.7-0.8, 1.05-1.20, 0.65-0.75 and 0.20-0.25, for the initial (15-20 days), development stage (25-35), mid-season (50-65 days), late-season (30-40 days), and at harvest stages, respectively. The first figure of each range denotes prevailing conditions of $RH_{min} > 70\%$ and $U < 5 \text{ m/sec.}$, while the second one for conditions when $RH_{min} < 20\%$ and $U > 5 \text{ m/sec.}$

FAO (1998) and Perrier and Salkini (1987) stated that $K_c$ represents the effect of four primary characteristics that distinguish the crop value from the reference grass ($ET_o$). It constitutes crop height (aerodynamic resistance), albedo (reflectance of crop-soil surface), canopy resistance (such as leaf and stomata characteristics), and evaporation from exposed soil surface. It is affected by the method used for determining $ET_o$ and site specific factors particularly those related to crop.
2.7.2 Methods for calculating ET_{crop} based on ET_{o}

Doorenbos and Pruitt (1977); Michael (1978); and FAO (1998) elaborated on the following methods for predicting ET_{o}:

2.7.2.1 Blaney-Criddle method

Based on observed correlation between seasonal consumptive use (CU) by crop and daily temperature and light hours, Blaney and Criddle (1950) stated the following formula:

\[ CU = \Sigma K \cdot f = \Sigma K \cdot (P \cdot t/100) \]

Where:

- CU = seasonal consumptive use of water
- K = empirical crop coefficient for a given month
- f = p.t/100
- t = mean monthly temperature, F°
- p = monthly daylight hours, % of year total
However, due to many limitations regarding variations in crop coefficient and CU with location and climatic conditions, Doorenbos and Pruitt (1975) modified this method, and $ET_o$ was first calculated by interpreting climatic, crop and site factors;

$$ET_o = C \left[ P \left(0.46 \times T + 8\right)\right] \text{ mm/day}$$

Where:

- $ET_o$ = reference crop evapotranspiration (mm/day) for a month
- $T$ = mean daily temperature ($^\circ$C) for one month
- $P$ = mean daily % of total annual day time hours at a given month and latitude (tabulated).
- $C$ = adjustment factor depending on $RH_{min}$, sunshine hours and daytime wind estimates.

However, this method is not suitable for climates with extreme sunshine fluctuations, high altitudes, small islands and equatorial regions.

### 2.7.2.2 Penman method

It is basically developed by Penman to estimate evaporation from free water surfaces in 1948. It was further modified to provide evapotranspiration estimates for crops. Predetermined crop factors by Penman varied from 0.60 in winter months and 0.80 in summer months of England were available. However, local crop factors may be used. It was found suitable in both arid and humid regions under calm weather conditions but with tedious calculations, as many meteorological data are needed. Doorenbos and Pruitt (1975) proposed the modified Penman method which comprises two major terms; the energy (radiation) term and the aerodynamic (wind and humidity) term to cater for climate
fluctuations (calm and windy) in cool humid regions and hot arid regions. ETo is expressed in modified Penman as follows:

\[
\text{ET}_o = C \left[ W \cdot R_n + (1-W) \cdot f(U) \cdot (e_a - e_d) \right] \text{ mm/day}
\]

Where:

- \( \text{ET}_o \) = reference crop evapotranspiration (mm/day)
- \( W \cdot R_n \) = radiation term:
  - \( W \) = temperature-related weighing factor
  - \( R_n \) = net radiation equivalent evapotranspiration, mm/day
- \( R_n = R_{ns} - R_{nl} \):
  - \( R_{ns} \) = the net incoming shortwave solar radiation
    \[
    R_{ns} = Ra (1-\alpha) (0.25 + 0.5 \frac{n}{N})
    \]
  - \( Ra \) = extra-terrestrial radiation, mm/day
    \[
    \frac{n}{N} = \text{ratio of actual sunshine hours (n) to maximum sunshine hours (tabulated)}
    \]
  - \( \alpha \) = reflection coefficient (taken 0.25 for most crops)
- \( R_{nl} \) = the net longwave radiation
  \[
  R_{nl} = f(t) \cdot f(\text{ed}) \cdot f(\frac{n}{N}) \text{ values of which are tabulated.}
  \]
- \( (1-W) \cdot f(U) \cdot (e_a - e_d) \): aerodynamic term:
  - \( f(U) \): wind-related function
  - \( e_a - e_d \): difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in mbar.
- \( C \) = adjustment factor to compensate for the effect of day and night weather conditions.

2.7.2.3 Radiation method
This method considers air temperature, sunshine, cloudiness or radiation, with general knowledge of levels of mean humidity and daytime wind. It is more reliable in areas that are not suited to Blaney-Criddle method. Radiation method expresses ETo as:

\[
E_To = C \times (W \times Rs) \text{ mm/day}
\]

Where:

- \(E_To\) = reference crop evapotranspiration, mm/day
- \(Rs\) = solar radiation in equivalent evapotranspiration (mm/day).

It can be obtained from sunshine records as:

\[
Rs = (0.25 + 0.50 \frac{n}{N}) Ra
\]

- \(W\) = weighing factor depending on temperature and altitude (tabulated)
- \(C\) = adjustment factor depending on mean humidity and daytime wind conditions.

### 2.7.2.4 Pan evaporation method

Despite all the discrepancies concerning variations in water loss from evaporation pans as compared to crop, but still \(E_To\) can be reliably calculated from a properly sited pan when mean pan evaporation (\(E_{pan}\)) is related to an empirically derived pan coefficient (\(K_p\)) as follows:-

\[
E_To = K_p \times E_{pan}
\]

However, much care should be given to pan design and characteristics, type and condition of bare soil, vegetation of the surroundings and climatic zone, as it affects \(K_p\).

Doorenbos and Pruitt (1977) mentioned that, the choice of method is based on the type of climatic data available, and the required accuracy. The modified Penman method would offer the best results
with minimum possible errors of ± 10% in summer, and up to 20% under low evaporative conditions, and could be applied for periods as shorter as 10 days, beside it requires conventional climatic data measurements. Other methods have greater possible errors particularly in extreme conditions and require measured data such as cloudiness and radiation (Pan and radiation methods). Others should only be applied for periods of one month or longer (Blaney-Criddle Method).

Michael (1978) generally expressed water requirements of a crop (WR) in terms of three components, such that:

\[ WR = Cu + \text{application losses} + \text{special needs} \]

A major special need comprises leaching requirements, while major sources of WR comprise irrigation requirements (IR), effective rainfall (ER), and ground storage (S).

Therefore, field irrigation requirements of a crop (IR):

\[ IR = WR - (ER + S) \]

This amount (IR) need to be applied accurately without excessive wastage, as water is the most valuable asset of irrigated agriculture. Michael (1978) reported four groups of devices of most common use in measuring irrigation water at farm level, for accurate application and distribution. These are:

i- Volumetric measurements by using container of a predetermined volume for small streams.

ii- Velocity-area methods, which include float method, current meter method, water meters.

iii- Tracer method.

iv- Measuring structures; orifices, flumes and weirs, which are commonly used at farm level. The rate of flow is measured
directly by reading a scale on the device, and the discharge rate is computed from standard tables or calibration curves, or standard formula. They give accurate and reliable results when properly sited and operated. The selection of either of devices depends on expected flow rate and site conditions.

Carruthers and Clark (1983) stated that, even for irrigated agriculture, it is difficult to match supplies exactly to predetermined seasonal demands of crop. Moreover, an irrigation regime that provides soil moisture for maximum crop growth and yield/ha will be unlikely to produce maximum output/unit of water.

2.8 Effect of tillage and irrigation practices on wheat production
2.8.1 Effect of tillage and seedbed practices

Liebharo (1995) reported from a 12-year test results that, wheat plants are influenced in all their development phases by physical soil changes (including density, pore volume and distribution, as well as aggregate stability) caused by tillage. But these soil changes however, have a significant but slight effect on its grain yield.

Aslam et al. (1989) and Ahmed et al. (1994) stated that, although no-till production enables timely wheat planting (before November 20), better weeding, and significantly higher number of tillers/m², but the technique is equivalent to conventional plough-till systems with respect to grain yield, and economical only in terms of resource use. Zentner et al. (2002) concluded that, during 12 years of experimentation, grain yield of irrigated spring wheat was rarely significantly influenced by various tillage methods in three types of soils, viz. clay, silt loam and sand.
Roy et al. (1992) reported that, tillage effects on wheat grain yield, averaged over irrigated and rainfed conditions were similar. Emergence %, number of spikes, grain yield, and most other yield components showed lower performance on no-till treatments compared to conventional plough-till. Singh et al. (1998) stated that, for many years, taller spring wheat plants, with larger and heavier ears, more grains/ear, and higher grain yield for flat sown conventional plough-till were obtained in India, compared to no-till systems.

Modestus (1994) reported that, wheat yields under chisel and disc plough practices in tropical Tanzania did not differ significantly for many years. However, chisel practices are less expensive with irrigation. Hamel (1995), for 10 years with irrigated spring wheat, observed that, both chisel and disc plough systems have slightly outyielded no-till systems, but significantly (P < 0.05). Grain yields were 108 and 122% more, respectively. Guy and Cox (2002) found that, wheat crop managed by chisel system, outyielded both disc plough and no-till systems under irrigation, and averaged 5.15 t/ha of grain.

Maurya (1989) stated that, no-till and tilled treatments did not give any significant differences in irrigated wheat performance in a sandy loam soil. But in a sandy soil, no-tilled plots had significantly lower grain yield.

Wilkins et al. (1989) generalized that, success or failure of a wheat crop depends on seedbed environment created by weather, history of management, in addition to tillage and planting practices. Mahboubi et al. (1993) agreed with this statement and described it as being the main reason making tillage effects contradictory and confusing. They also stated that, stand establishment is often the only criterion used to quantify and evaluate the performance of planting and tillage systems.
Reeder (1989) stated that ridge planting improved yields, especially on poor drained compacted clay soils. It controls erosion and reduces operating and labour costs.

Mahdi et al. (1998) mentioned that, establishment of wheat plants sown in ridges was poor than that on flats, causing reduction in number of tillers, leaf area index (LAI), and final grain yield which was 40% lower. Roy et al. (1992) generalized that, line planting super yielded broadcasting method due mainly to high number of tillers and ears/m².

2.8.2 Effect of irrigation practices

Saffaf (1980) stated that, with the decreasing water resources, and increasing water losses and demands in semi-arid regions where irrigated agriculture is practiced, the main possibility to alleviate these impacts is by increasing water use efficiency (WUE) of cultivated crops. Gurouch (1980) mentioned that, this parameter (WUE) tend to vary considerably with water application method and soil type. It was low in surface-furrow irrigation due mainly to poor irrigation practices at farm level. Moreover, Radcliffe et al. (1988); Edwards et al. (1989); Saleh and Hanks (1989); Trout (1992); Meek et al. (1992); Benjamin et al. (1994); and Christensen et al. (1994) reported that efficient irrigation design and management techniques are required for optimum utilization of the scarce water resources, particularly in surface-furrow irrigation due to its low efficiency in arids, semi-arids, and sub-humids. Water losses may reach 57% during water conveyance, due mainly to deep percolation and evaporation as a direct result of lack of knowledge of field and hydraulic parameters related to the process. However, Michael (1978) stated that furrow irrigation suits most soils except sands as due to their very high infiltration rates and poor lateral distribution of water
between furrows. Nevertheless, it reduces pudduling, crusting, evaporation losses, erosion hazards and labour requirements, when proper land grading is guaranteed even under small water streams.

Michael (1978) and Meek et al. (1992) stated that increased depth of water, particularly in surface irrigation (furrow or flat beds) results in temporal increase in initial infiltration rate which lasts soon. Also, increased infiltration in the tropics is aided by decreased viscosity of warm water. Similarly, Baumhardt and Lascano (1996) specified that, when surface irrigation is practiced, infiltration is not affected by seedbed configurations of either bed furrows or bed flat types at a given soil type. However, in a clay loam, furrow beds had better management efficiencies at smaller streams of water.

Musik et al. (1994) stated that two processes are involved with crop-water relations, viz. water uptake that depends on root and soil, and ETc which is positively related to grain yield of wheat. Doorenbos and Kassam (1986) stated that, crops vary in their growth and yield response to water shortage as manifested on total utilization efficiency (kg/cm³) for harvested yield (Ey), or total harvested portion of dry matter (harvest index, HI). Values of harvest index for high yielding wheat cultivars at ideal irrigated conditions are 0.35-0.45 on dry weight basis. Mohamed (2000) highlighted similar findings. Moreover, leaf area index was reported by Moustafa et al. 1996 as the most affected physiological process to water stress up to 60 days after sowing. However, for standard crop, leaf area index is assumed to be five times the ground surface. Moreover, Ey, in kg/m³ was estimated as 0.8-1.0, at grain moisture of 12-15% (Doorenbos and Kassam, 1986).

Carruther and Clark (1983) stated that, particularly for wheat, irrigation water complements other technical inputs which when applied
together, the yield response is greater than the sum of individual responses when inputs were applied independently.

Basic interaction between tillage-crop-water relations was mentioned by Doorenbos and Kassam (1986) and Aggrawal and Sharma (2002) such that, under deep and shallow tillage treatments 56.5-72% of wheat root mass was accumulated in 0-5 cm layer, 18-32% in 5-15 cm layer, and 10-18.5% in the 15-25 layer. However, for water uptake, up to 50-60% of total water uptake occurs from the first 0.30 m, 20-25% from the second, 10-15% from the third, and < 10% from the fourth. Salih et al. (1992) concluded that, the rooting depth of wheat under irrigated central clays of the Sudan, never exceeds 0.28 m. Therefore, cultivars with heavy rooting density in such semi-arids, could use and extract more water from deeper depths, which results in better grain yields.

Total water requirements per season for spring wheats were estimated by different workers. Carruther and Clark (1983) stated 740-880 mm, while Doorenbos and Kassam (1986) reported 450-650 mm. Pandey and Pal (1973) mentioned that, the conventional irrigation regimes of 5-7 irrigations with total of 450 mm of water per growing season were satisfactory. However, the most critical stages to water deficits are anthesis (heading) and grain filling, 69 and 95 to 102 days after sowing, respectively. Doorenbos and Pruitt (1986) reported similar observations such that, sensitivity to water deficit in spring wheat is as follows, flowering > yield formation (grain filling) > vegetative period. Carruther and Clark (1983) specified that, for spring wheats grown at mid November (winter), total water requirements, $ET_c$ in the Sudan as 6.30 mm/day averaged over the hottest months, vs. 4.70-5.00 mm/day in India.
Hubbard (1982) reported that, for a good wheat crop producing about 7.00 t/ha of grain, and with a harvest index of 0.45, a total water supply of > 375 mm is needed during its $3^{1/2}$ month of life (3750 m$^3$/ha).

Moursi et al. (1979) observed up to 43% decrease in wheat yield assessed from yield components, when soil moisture stress was increased beyond 25%. They concluded that irrigation had the most serious effect on grain yield when applied from booting (flowering) onwards. Hussein et al. (1978); Mishra et al. (1995); and Pal et al. (1996) stated that, the general trend in irrigated spring wheat production in Egypt and India is that, values for plant height, number of fertile tillers/m$^2$, spike weight, grain weight/spike, 1000 grains weight, total grain and straw yield/ha, increase with increasing number of irrigations from 3 to 7, up to 94 days after sowing. Pal et al. (1996) also mentioned that, during a 3 years’ experimentation, increased irrigation maintained higher wheat leaf area index, dry matter, and grain yield. Highest crop coefficient (1.00) was recorded in January for timely sown wheat (mid November). It used 2.84 mm/day to produce 3.185 t/ha in 118 days with WUE of 9.49 kg/ha-mm water. Peak WU rate, mm/day coincided with flowering stage (1$^{st}$ week of February).

Thakur (1987) and Guerra (1995) stated that yield components that causes reduction in grain yield as due to water deficits during the season are, the number of spikes/m$^2$, number of spikelets/spike, number of grains/spike, but differences in 1000 grains weight were not significant. Rawson (1986) emphasized on number of tillers/plant and he concluded that under tropical farming conditions of wheat, 1.5-2.00 tillers/plant are reasonable and common. Hochman (1982) found 28, 36, and 16% lower grain yields than 100% ET$_c$, when < 70% ET$_c$ irrigation water was applied, from tillering to anthesis; from booting to grain
filing; and during grain filling, mainly due to, reduced LAI + grain number; grain number + 1000 grains weight; and 1000 grains weight only, respectively. He concluded that, WUE is lowest between booting and grain filling, and the latter is the most critical.

2.9 Effect of tillage and irrigation practices on Sudan wheat production

Faki (1995) stated that, although up to 43% (0.528 m.ha) of the cultivated area in the irrigated sector is devoted annually to wheat, but due to limitations related to irrigation water, 30% of the area would receive lower production inputs which will finally affect productivity. However, yield variations across Sudan are generally due to management (inputs) or higher winter temperatures, with time and location. Taha (1990) and Faki and Ismail (1992) pointed out that, location variabilities include soils, land leveling, type of proceeding crop and weeds while management variabilities were mainly related to tillage intensity and quality, as well as irrigation management.

Babiker and El Hassan (1990); Satti (1990); Taha (1990); Saleh et al. (1992); Dawelbeit (1995); Nasr and Selles (1995); Bouaziz and Bruckler (1997); and Dawelbeit and Babiker (1997) stated that, one of the major problems of growing wheat in tropical heavy clays is poor crop establishment attributed to inadequate land preparation and method of sowing. Ageeb (1994) considered cultural practices like late sowing, poor water management, and delayed harvest as prime reasons for yield fluctuations.

Babiker and El Hassan (1990); Omer (1990); Satti (1990); Dawelbeit et al. (1992); and Dawelbeit (1995) reported that, various tillage practices were adopted everywhere for irrigated wheat production
in Sudan, depending on availability rather than suitability of implements. Dawelbeit et al. (1992) stated that, the effectiveness of each tillage system in improving wheat yield is unknown as information regarding performance is lacking. However, the recommended systems include two disc harrowings, and ridging followed by disc harrowing. They were practiced in 48 and 52% of total wheat area in Gezira, respectively, as well as all over New Halfa. Dawelbeit et al. (1992b) considered disc harrow (twice harrowing) to be effective in the heavy clays of central Sudan as it maintains good soil aggregation.

Satti (1990) tested two ridger systems, viz. ridging followed by either split ridging (RSR), or disc harrowing (RDH), + two sowing methods; in flat, and 80 cm ridges. Statistically, no significant differences in wheat grain yields as due to any treatment was observed. However, ridge planting numerically outyielded flat sowing in terms of grain yield and higher crop stand, possibly due to better control of irrigation water and less water logging. He also studied the same tillage treatments, but with 40- and 80-cm ridges, and chisel plough (flat) sowing, and obtained similar results with respect to yield and yield components. Corresponding values for number of effective tillers/m², number of seeds/spike, 1000 grains weight, stand plants/m², and plant height at harvest were 341-716, 24-35, 28-32 g, 196-338, and 30-67 cm, respectively. Dawelbeit and Babiker (1997) studied two methods of land preparation; namely, disc plough and disc harrow, followed by leveling, with three methods of sowing; drilling (20 cm), broadcasting, and broadcasting followed by 80 cm ridging, with conventional irrigation. None of growth parameters; plant height (cm), number of spikelet/head, and number of seeds/spikelet were significantly affected (P < 0.05) by either of treatments in both seasons. They averaged; 63.8 cm, 14.7 and
1.8 in the first; and 52.9 cm, 15.9 and 1.8 in the second season, respectively. However, broadcasting gave the lowest number of plants, number of heads, and weight of seeds/m². They were increased by ridging x disc harrow system, which gave higher grain yields than disc plough system that are significant (59% more) and non-significant (11% more) in the first and second seasons, respectively. Disc plough on the other hand, consumed more fuel, had low work rate, and was more expensive. They recommended disc harrow system for better and economical performance. Ridging gave significantly higher yields than broadcasting in both seasons, mostly due to loss of seeds during the first irrigation when water escapes into cracks, as well as shallow depth of sowing in flat system. Ridge planting provided better seedbed and better irrigation water management.

Omer (1990) observed that, in fields where wheat is ridge-planted, the crop was less affected by water logging and gave better yields than flat-sown plots. Ridge-planted crop exercised a significantly better stand, greater number of heads/m² (P < 0.01) and number of plants/m² (P < 0.05), which directly affected grain yield. Farah et al. (1998) confirmed the ill-fates of water logging when he recorded up to 30-40% irrigation water in excess of the actual CWR in areas of good access to water, which resulted in significant losses in wheat yields in the Sudan Gezira. Taha (1990) also highlighted the effect of impeded water management practices when he tested both ridge and flat sowing relevant to conventional surface irrigation in central Sudan. Although he did not observe any significant differences in grain yield, but 7% more yield was obtained with ridge planting due mainly to improved crop establishment. Number of plants/m² were also significantly (P < 0.05) higher (44% more), as well as number of seeds/head (P < 0.05).
However, number of heads/m² and 1000 grains weight were statistically similar (349 vs. 307; and 44.2 vs. 41.1 g for flat and ridge beds, respectively). Generally, average weight (g) of 1000 grains for plough-till farming was in the range of 34.0 to 37.0 as reported by Babiker et al. (1991) in Sudan Gezira; and Ghorashi (1990) and Abdel Gadir (1994) in New Halfa.

Babiker and ElHassan (1990) stated that dry wheat sowing on flat and ridge, when wide level disc and ridger followed manual seed broadcasting, respectively resulted in slightly better but not significant grain yields with flat sowing. They reported better crop establishment resulting from higher plant stands and better weed control from ridge sowing under wetting conditions. Dawelbeit et al. (1992b) studied many sowing methods, viz. drilling, wide level disc, wide level disc with no feed tubes followed by light disc harrow, ridger, and finally heavy tool bar with corrugations to cover seed. They did not report any significant effect of seeding methods in Sudan Gezira, Rahad, New Halfa, and Blue Nile. However, flat sowing (wide level disc without feed tubes) reported numerically the least grain yield in all stations. On the other hand, Salih and Musa (1989); Salih et al. (1990); and Babiker and Mohamed (1992) stated that, ridge sowing tended to improve water management and decreased flooding hazards, but did not increase grain yield significantly when compared with flat sowing.

Farah et al. (1992) stated that significant grain yield differences in wheat are generally due to high number of grains with scheduled irrigation intervals. Farah et al. (1995) did not report any significant reduction in grain yield due to 50 and 75% moisture depletion at Sudan Gezira. However, Farah (1995) mentioned that, for maximum allowable grain yield, moisture stress should be avoided at the time of booting
(flowering) and anthesis. Ishag (1995) reported that, for timely sown wheats (mid November) in central Sudan clays, water stress has the least effect on yield and yield components, particularly for number and weight of grains and ears. Farah et al. (1994) also stated that, at certain developmental stages either negative or no impacts as due to water shortage would be reflected in economic yield. However, maximum yields were obtained with higher water status treatments throughout the growing season (up to 6000 m³/ha) with maximum WUE. Significant increments in grain yield of wheat based on WUE maximization were reported by Ahmed (1992), Farah et al. (1993); Farah et al. (1994); Farah (1995); and Ibrahim (1995). Higher values of WUE were also obtained by saving 530-1350 m³ of irrigation water/ha one month before harvest, but significant reduction in yields (33%) occurred when stressing for water was practiced 50-60 days after sowing (at heading).

Generally, Farah et al. (1994) mentioned that, current water management practices resulted in water losses through deep percolation by more than half the amount added particularly during the last irrigations which sometimes amounted to 2336 m³/ha.
CHAPTER THREE
MATERIALS AND METHODS

3.1 Location

In an attempt to investigate the effect of irrigation regime and tillage system on the growth and yield of wheat, experiments were conducted for three successive seasons; 2000/01, 2001/02 and 2002/03 at the demonstration farm of the Faculty of Agriculture, University of Khartoum, Shambat. The area lies at longitude 32° 32’E, latitude 15° 40’N, and altitude 380 amsl. The climate is described as being semi-arid.

3.2 Design and layout of the experiment

A strip-split plot design was adopted to evaluate the effect of five tillage (T) systems (vertical or strip-plot factor), three water (W) amounts (horizontal or split-plot factor), and two seeding (S) methods (strip-split plot factor) on growth and yield of common bread wheat (*Triticum aestivum* L.).

Tillage treatments (T) comprised the following systems:-

i- Disc harrow system (*T*$_1$)

ii- Ridger system (*T*$_2$)

iii- Chisel plough system (*T*$_3$)

iv- Disc plough system (*T*$_4$)

v- No-till (*T*$_5$)
Water amounts (W) or the horizontal factor included three irrigation regimes expressed in terms of crop evapotranspiration (ET<sub>c</sub>) as follows:-

i- 100% ET<sub>c</sub> (W<sub>1</sub>)

ii- 80% ET<sub>c</sub> (W<sub>2</sub>)

iii- 60% ET<sub>c</sub> (W<sub>3</sub>)

The modified Penman (1977) formula was used to calculate ET<sub>c</sub> predicted from meteorological data, periodically obtained from Shambat Meteorological Station, and further processed.

Seeding (s) methods comprised two treatments,

i- broadcasting, S<sub>1</sub>

ii- ridge planting, S<sub>2</sub>

**Fig 3.1 illustrates the layout of the experiment.**

Net area of experimental unit (plot) = 4.5 x 6 m<sup>2</sup>

total area of experimental units = 4.5 x 6 x 72 = 0.194 ha

gross experimental area = 86 x 64 = 0.55 ha

### 3.3 Cultural practices

#### 3.3.1 Tillage and seeding

*Implements used for executing tillage treatments and preparing the final seedbed for seeding include;*

i- A 180-cm wide offset disc harrow was used for the corresponding system (T<sub>1</sub>). The implement has two gangs equipped with light discs of an average diameter of 52 cm. discs of the front gang were notched, while those of the rear one were plane.
Fig. 1
ii- A 3-boddied ridger was used in the ridger treatment (T₂), with its ridging bodies attached to a rigid tool bar frame and spaced at 70 cm (Plate 3.1).

iii- For T₃, a two-row, 5-shanked chisel (3 shanks in the front gang) was used to provide a theoretical width of 142 cm (shanks were 28.4 cm apart) as shown in Plate 3.2.

iv- A standard 3-bottom disc plough was used for the fourth treatment (T₄). Mean diameter of discs was 64 cm (Plate 3.3).

All four implements, which were described previously, were fully mounted implements on the tractor 3-point linkage. Primary tillage was executed early in October in each season. Except for no-till treatment, a light harrow + leveling followed all other primary tillage operations each season before the start of seeding procedures. A Massey Ferguson (MF 165) tractor, of maximum horse power of 77 HP was used as the power source in this study.

Preparations for seeding started in early November. Certified wheat seeds, Elneelein cultivar, was brought from Hudeiba Research Station and used. Germination test was carried regularly before the material is decided for use at field level. Seed rate (g/plot) was determined, depending on the per hectare rate of 143 kg as follows:-

\[
\text{Seed rate/plot (g)} = \frac{143 \text{ kg/ha} \times \text{plot area (m}^2\text{)}}{10} \quad \text{eq. (3.1)}
\]
The material was then carefully weighed using a sensitive balance and kept in individual polythene bags before seeding.

Plate 1
Plate 3
For ridge planting, experimental plots were prepared using the ridger implement previously mentioned, and seven ridges/plot were established. A wooden peg “Kholal” was used to open two grooves along each ridge, one on each side at a 20 cm distance from the base of the ridge.

During planting, seeds were manually broadcasted and raked for uniform distribution and covering within each plot. In ridge planting treatment (S₂), seeds were also manually drilled and covered in each groove. Planting was done at mid November each season. The first irrigation followed planting operation immediately to restore seeds and urea fertilizer in each plot. Enough water was applied to meet the filling requirements of cracks and other voids, as well as to sustain the seed for germination. A light irrigation was applied one week after the conventional one to guarantee efficient germination. It represents the first irrigation based on calculated crop evapotranspiration (ETₑ).

3.3.2 Irrigation water measurement and application

A set of 90° V-notch weirs was locally made at the workshop of the Department of Agricultural Engineering at Shambat, according to Michael (1978) and used to measure the amount of water (ETₑ%) assigned for each plot (Plate 3.4). Excluding the first conventional irrigation, seven irrigations were applied on consumptive use basis with the aid of weirs. To facilitate irrigation, a single weir was set permanently at the head of the inlet of each irrigation canal assigned to irrigate a total of 24 experimental units (plots) lying in alignment.
Plate 4
across all replications (Fig 3.1). The level of water over the V-notch was kept at 15 cm, and the volume of water applied through the weir was calculated in terms of water discharge (ℓ/sec) as follows:-

\[ Q = 0.0138 H^{5/2} \]  

(3.2)

Where:

\[ Q = \text{discharge of weir (ℓ/sec)} \]
\[ H = \text{head of water over the V-notch (cm)} \]

The discharge values presented by Michael (1978) were used to calculate the time (t, min.) required for a given volume of water (V, m³) needed at each irrigation at the plot level depending on that head (H, cm). Therefore, at a given water head (cm), the time needed to add a predetermined volume (m³) of water to a given plot was:

\[ t (\text{min.}) = \frac{V \ (\text{m}^3) \times 1000 \ (\text{ℓ}/\text{m}^3)}{Q \ (\text{ℓ}/\text{sec.}) \times 60 \ (\text{sec.}/\text{min.})} \]  

(3.3)

Where:

\[ Q = \text{discharge of water flowing at height H (cm) over the V-notch.} \]

The amount (V, m³) assigned for a plot was determined as follows:

\[ V \ (\text{m}^3) = \frac{K_e \cdot ETo \cdot I \cdot A}{1000 \times e} \]  

(3.4)

Where:-

\[ V = \text{volume of water to be applied per irrigation, m}^3. \]

\[ K_e = \text{crop coefficient (dimensionless) which was calculated according to Doorenbos and Pruitt (1977) depending on crop developmental stage.} \]
$\text{ET}_0 \cdot I = \text{total potential evapotranspiration (mm/14 days) calculated according to Doorenbos and Pruitt (1977) from meteorological data (for more details, sample calculation was presented in Appendix A).}$

$\text{ET}_o = \text{daily potential evapotranspiration (mm/days).}$

$I = \text{Irrigation interval (14 days)}$

$A = \text{experimental unit (plot area, m}^2\text{)}$

$e = \text{irrigation efficiency (%) comprising mainly application and distribution efficiencies. It was considered to be 0.70 for furrow irrigation.}$

3.3.3 Cultural practices

**Nitrogen fertilizer in form of urea was applied at sowing to provide IN (95 kg/ha).**

Weeding was done manually depending on weed intensity. However, 1 - 2 weedings/season was the general trend.

Harvesting was carried out during the first week of March each season.

In the first season, the experiment was laid with three replicates, making a total of 72 experimental units.

3.4 Determination of soil physical properties

3.4.1 Determination of soil moisture content (%)

Soil moisture content (SMC) was determined using the common method described by Gardner (1965). Soil samples were taken after the final preparation of seedbed, but before sowing. Samples from three different locations representing a single tillage treatment were taken from three successive soil depths (20 cm increments from soil surface) with an aid of an auger. Samples were immediately kept in a pre-
labeled polythene bags before taken to the laboratory. Three sub-
samples were taken from each depth, weighed in sensitive balance \((W_1)\),
oven-dried overnight at 105°C and the oven-dry weight \((W_o)\) was
determined.

\[
\text{SMC\%} = \frac{W_1 - W_o}{W_o} \% \quad \text{...............} (3.5)
\]

**3.4.2 Determination of soil bulk density (g/cm³) and % pore space (porosity)**

Procedures stated by Blake (1965) and Baver *et al.* (1972) were
used to determine soil bulk density \((b.d)\) and % pore space (porosity),
respectively. Undisturbed soil clods were taken from each tillage
treatment (strip) with aid of an auger, at similar depths which were
mentioned previously, packed, labeled and taken to the laboratory.
Three sub-samples in form of undisturbed clods were considered for
each soil depth. Clods were initially weighed \((W_1)\) and carefully coated
with paraffin wax of known density \((d)\) before reweighing \((W_2)\).
Volume of the clod \((V)\) was then determined by dipping or soaking the
sample in tap water and recording the volume of the displaced water.
Soil bulk density was then determined as follows:-

\[
\text{Bulk density (g/cm}^3) = W_1 \left[ \frac{V - (W_2 - W_1)}{d} \right] \quad \text{...............} (3.6)
\]

\[
\text{% Pore space} = \frac{(b.d) \%}{p.d} \quad \text{...............} (3.7)
\]

**Where:**

\(b.d = \text{bulk density of soil (g/cm}^3)\)
p.d  =  particle density of the soil sample (g/cm$^3$)

d  =  density of paraffin wax (g/cm$^3$)

3.4.3 Determination of infiltration rate ($\ell$/t)

The procedure reported by Michael (1978) was followed using the double ring infiltrometer method, which comprises two steel cylinders set concentrically into the soil just after the primary tillage operations ($T_1$, $T_2$, $T_3$ and $T_4$), and before plot shaping for no-till treatment. Diameters of cylinders were 60 and 30 cm for the outer and the inner one, respectively. Cylinders were driven in succession into the soil to a depth of 10 cm by striking on a wooden board, placed across the top of the cylinder. The wooden board served as a mean to protect cylinder edges and maintain smooth hammering and driving operations. Before adding water to the cylinders, a polythene sheet was placed inside each cylinder to prevent pudding and deformation of the initial settling of soil particles. Water of the out cylinder was used as a buffer to prevent lateral seepage from the inner one. The initial level of water in the inner cylinder was restored with aid of a scale fixed tightly to the inner wall. Water level in both cylinders was kept the same. Infiltration (cm/min.) was recorded every 5 minutes before the initial water level was restored. Measurements were replicated two times only for each tillage treatment and averaged.
3.5 Machine performance parameters

Machine parameters that relate to its performance included field capacity (C, ha/h), fuel consumption (l/h, l/ha), and power-related parameters [draft (D, kN), drawbar power (DBP, kW), and wheel slippage (%)].

3.5.1 Field capacity of machine

Parameters related to this variable included the working speed (S, km/h), working width (W, m), and field efficiency (e, %). Ploughing depth (cm) was related to time effectiveness in doing a certain job and power requirements of a machine [e.g. unit draft (kN/cm²)].

3.5.1.1 Working speed

It was determined by relating the time (average of three replicates) needed for a complete trip along a predetermined distance (AB). A stop watch, two stakes (or poles), and a measuring tape were used, and the average speed was estimated using the following formula:-

\[ S \text{ (km/h)} = \frac{\text{distance (m)}}{\text{Average time (min)}} \times \frac{60}{100} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.8) \]

3.5.1.2 Working (ploughing) width

Average width (W, m) was taken from three working trips lying side by side at field level. A measuring tape was used to measure the widths.

3.5.1.3 Field efficiency
Field efficiency (e, %) s determined by relating effective (net or productive) time (te) and gross time (tg) consumed in performing a given operation: -

\[ e (\%) = \frac{te}{tg} \times 100 \% \] \hspace{1cm} (3.9)

Where:

- \( te \) = effective or productive time (h)
- \( tt \) = time for turning at head lands (h)
- \( t_{int} \) = time for interruption (casual stoppage), (h)

A stopwatch was used to determine the stated kinds of time.

Field capacity (C) would therefore be determined as theoretical (CT) or effective (Ce) capacity as follows: -

\[ CT (\text{ha/h}) = \frac{S.W}{3.6} \] \hspace{1cm} (3.10)

\[ Ce (\text{ha/h}) = CT \cdot e = \frac{S.W \cdot e}{3.6} \] \hspace{1cm} (3.11)

Where:

- \( CT \) and \( Ce \) = theoretical and effective capacities (ha/h), respectively
- \( S \) = rated working speed (km/h)
- \( W \) = rated working width (m)
- \( e \) = time efficiency (%)
At three different stations along a ploughing strip, the soil was carefully removed by hand till the surface of the unploughed zone was reached. A uniform board or rectangular object was placed on the top of the ploughed surface and at right angle to the ploughed sheet. With aid of a scale, the vertical distance between the soil surface and the surface of the unploughed layer underneath, was determined to represent ploughing depth.

3.5.2 Fuel consumption (l/h, l/ha)

The refilling procedure was used for determination of fuel consumption. It implies the determination of the volume of the fuel consumed on time- or area-basis, by restoring the initial level in the fuel tank of tractor by adding fuel for refilling with aid of a measuring cylinder. Once the consumed volume \( V \) of fuel was determined, fuel consumption will be:

- fuel consumption on time-basis (l/h):
  \[
  \text{volume of fuel} \ (l) \times 60 \quad \text{(3.12)}
  \]

- fuel consumption on area-basis (l/ha):
  \[
  \frac{\text{volume of fuel}}{\text{total area (m}^2\text{)}} \times 10000 \quad \text{(3.12)}
  \]

3.5.3 Power-related parameters

3.5.3.1 Total draft (D, kN)

The most commonly used method was that stated by Hussein and Sarker (1978). A 100 kN-max. capacity, spring type dynamometer (Plate 3.5), Swedish make, was used to determine the total draft (kN) requirements of tillage implements used in this
study. Two tractors, a John Deere (JD) 2030, 75 HP, and Massey Ferguson (MF) 165, 77 HP were used to provide the pull requirements for the test. Two chains, a stopwatch, a measuring tape, and a set of poles were also used.

Plate 5.
The implement under test was attached to the JD tractor (auxiliary tractor) with its gearbox lever at Neutral when undertaking the test. The chains were used to connect the dynamometer with the two tractors. One chain connected the device to the drawbar of the leading tractor (MF 165), and the other connected it to the front frame of the auxiliary tractor (JD) to which the implement was attached. While the leading tractor (MF 165) was pulling the auxiliary tractor behind it, direct reading of draft from the device was obtained. Three readings for each test were made at three equidistant stations (5 m) along the track. Each test was replicated three times. Both effective draught (loaded tractor) and idle draught (unloaded), as well as total time needed to travel the predetermined distance of test were recorded. Two types of speeds were calculated:

\[
\text{- advance under load (km/h)} = \frac{\text{total distance (m)}}{\text{time under load (min)}} \times 60/100 \quad (3.14)
\]

\[
\text{- advance under no load (km/h)} = \frac{\text{total distance (m)}}{\text{time under no load (min)}} \times 60/100 \quad (3.15)
\]

Average reading for total draught (kN) was used to calculate both power requirements (kW) and unit draft (N/cm²) as follows:-

\[
\text{- DBP (kW)} = \frac{D \text{ (kN)} \times S \text{ (km/h)}}{3.6} \quad (3.16)
\]

\[
\text{- Draft/unit area (N/cm²)} = \frac{\text{total draft (N)}}{w \times d} \quad (3.17)
\]

Where:
w and d = ploughing width and depth (cm), respectively.

3.5.3.2 Travel reduction (%)

The formula stated by Sayed (1992) was used in this study to determine wheel slippage depending on advance rate (km/h):

\[
\text{Wheel slippage (\%) = } \frac{(\text{advance under no load} - \text{advance under load}) \%}{\text{advance under no load}} \quad (3.18)
\]

3.6 Growth and yield components

3.6.1 Growth components

Growth components which were considered in this study included:

3.6.1.1 Plant population (plants/m²)

Three weeks after sowing, the fully emerging healthy seedlings within an area of \(\frac{1}{16}\) m² were determined using a \(\frac{1}{4} \times \frac{1}{4}\) m² steel frame tossed twice in each broadcasted (S₁) plot, and plants were counted, averaged and processed on per square-meter-basis.

For ridge planted plots, two linear meters were considered randomly, one on each side of two randomly selected ridges. Plants were counted, averaged and considered on per square-meter-basis as follows:-
Plants/m² = number of plants / linear meter  \hspace{1cm} (3.19) \\
\hspace{1cm} 0.70

Assessment of this parameter and subsequent ones was carried out throughout the experimental units in all seasons and for all parameters, unless stated otherwise.

3.6.1.2 Plant height

With the aid of a 1.00-m long ruler, plant height was determined at 3, 6, 9, 12 weeks after sowing, and at harvest. Ten plants/each experimental plot, 3-5 of them which were tagged at first measurement were considered and measured to obtain average plant height.

3.6.1.3 Leaf area index (LAI)

At time of grain filling, a well stretched, fully extending middle leaf (3rd or 4th in order) of an upright standing ten plants in each plot were measured for length (l, cm) and width (w, cm) determination, and averaged. LAI was obtained as follows:

\[ \text{LAI} = 0.74 \times l \times w \times \text{number of leaves/plant} \times \text{number of plant/unit area} \] \hspace{1cm} (3.20)

3.6.1.4 Leaf turgidity

From each experimental plot, ten green, fully matured leaves were taken from randomly selected plants just before the last irrigation. Leaves were immediately kept in polythene bags, labeled, taken to the laboratory and weighed for fresh weight (W_f)
determination using a sensitive balance. Turgid weight \((W_t)\) was determined by weighing the material after soaking in tap water for 4 hours. The sample was then oven-dried for 24 hours at 80°C, and the oven-dried weight \((W_o)\) was then determined. Turgidity was obtained as follows:

\[
\text{Turgidity (\%)} = \frac{W_t - W_o}{W_t} \times 100\% \quad \ldots \ldots \ldots (3.21)
\]

3.6.1.5 Number of effective tillers/plant:

Ten plants/plot were selected randomly, and the productive tillers (heads)/plant were counted and averaged.

3.6.1.6 Number of tillers/m²

From each experimental plot, three random counts for productive tillers (heads) in an area of \(\frac{1}{16}\) m² were obtained as described in section 3.6.1.1.

3.6.1.7 Plant population at harvest

As described in section 3.6.1.1.

3.6.2 Yield and yield Components

This involved the determination of:

3.6.2.1 Number of spikelets/spike

Five plants/plot were randomly selected and their fertile spikelets were separated, counted, and averaged.

3.6.2.2 Number of grains/spike

3.6.2.3 Weight of grains/spike
Similar procedures as stated in section 3.6.2.1 were followed. Spikes were carefully threshed, and their grains were weighed, counted, and averaged.

3.6.2.4 Thousand-grains weight

From the sample that was taken for determining grain yield/plant, three samples, each of 1000 grain, were weighed separately in a sensitive balance and averaged.

3.6.2.5 Weight of spikes/plant

Spikes from ten randomly selected plants were carefully separated, weighed, and averaged to obtain average spike weight at each experimental unit.

3.6.2.6 Number of aborted spikelets/spike

Average number of aborted (empty) spikelets remaining from counts of section 3.6.2.1 was considered.

3.6.2.7 Harvest index

Ten randomly selected plants from each plot were carefully uprooted and taken to the laboratory for thorough drying before they were weighed ($W_i$). Spikes were separated, threshed, and grain weight (ton/ha) was determined. Roots were also trimmed.

Harvest index (HI, %) was obtained as follows:-

$$HI \,(\%) = \frac{\text{grain yield}}{\text{total yield}} \times 100 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.22)$$

3.6.2.8 Grain yield
A steel frame of 1 x 1 m², and a one-meter length ruler were used, each for its corresponding plot as stated in section 3.6.1.1. Plants were carefully harvested in bundles, labeled, and taken to the laboratory for threshing. Clean seeds were weighed and expressed in terms of ton/ha.

3.7 Water use efficiency (WUE, kg/m³)

Grain yield/plot was made in terms of kg/ha. Total volume of water applied to produce that amount of yield (m³/ha) was determined. WUE was then calculated as:

\[
\text{WUE (kg/m}^3\text{)} = \frac{\text{total yield (kg/ha)}}{\text{total volume of water (m}^3/\text{ha)}} \quad \ldots \ldots \ldots \ldots \text{(3.23)}
\]

All results were statistically analysed and presented in tabular or graphical forms.
CHAPTER FOUR
RESULTS

4.1 Effect of tillage on physical properties of soil

4.1.1 Effect on soil moisture content (db%)

Soil moisture content (SMC) within 0.60-m soil depth at the experimental site, just prior to tillage was shown in Fig. 4.1 for the three successive seasons.

It is evident that, SMC (db%) tended to increase with increasing soil depth in all seasons.

SMC (db%) just after harvest, described as residual SMC was considered only for flat beds of each tillage methods for the 1\textsuperscript{st} and 2\textsuperscript{nd} seasons (Tables 4.1a and 4.1b, respectively), as well as in Table 4.1c. These results revealed that, the deepest flat profiles of soil (0.40 – 0.60 m) retained more soil moisture than the upper or medium ones in both seasons. Moreover, residual SMC (bd%) obtained from plots that were treated with restricted water regimes (60% ET\(_c\)) was comparatively less than those treated with 100% - or 80% ET\(_c\) in both seasons. Ridger (T\(_2\)) and disc plough (T\(_4\)) flat profiles, on the other hand, have had the maximum storage capacity that averaged 22.40 and 22.28%, respectively.
Table 1a
Table 1b
4.1.2 Effect on bulk density

Average bulk density values as affected by different tillage methods and soil depth in the first and second seasons were shown in Tables (4.2a and 4.2b), respectively as well as in Fig. 4.2. Tillage treatments did not record any significant effect on bulk density within the prescribed range of soil depth (0.00 – 0.60 m) in both seasons. However, disc plough (T4) and no-till (T5) reported maximum numerical average bulk densities of 1.62 and 1.54 g/cm\(^3\); while chisel (T3) and ridger (T2) profiles gave the minimum numerical values of 1.44 and 1.45 g/cm\(^3\), in the 1\(^{st}\) and 2\(^{nd}\) seasons, respectively.

4.1.3 Effect on porosity

As shown in Tables (4.3a and 4.3b), there was no significant effect on porosity (%) as due to tillage treatments within the range of soil depth previously stated. But, as a general observation, porosity tends to increase with decreased bulk density (g/cm\(^3\)). However, chisel plough (T3) and offset disc harrow (T1) recorded the greatest numerical porosity values of 51.35% and 51.69%, respectively; while offset disc harrow (T1) and no-till (T5) reported the least porosity values of 45.95% and 48.31%, in the 1\(^{st}\) and 2\(^{nd}\) reasons, respectively.
Fig 2
Table 2a
Table 4.2b
Table 4.3a
4.1.4 Effect on infiltration characteristics

Figs. (4.3a and 4.3b) show the characteristic trend of infiltration rate (cm/h) observed during the first and second seasons, respectively. In the first season, it is evident that, the initial infiltration rate was greater in disc plough profiles (23.16 cm/h); followed by ridger (18.00 cm/h), while no-till reported the least infiltration rate of 11.30 cm/h.

Abrupt drop in infiltration rate was reported 10 minutes later, in the same prementioned order. The corresponding values of their infiltration rate were 11.16, 7.20 and 6.24 cm/h, respectively.

Basic infiltration rate on the other hand was reached after 35 minutes only from the start of the process in both chisel plough (T₃) and no-till (T₅) profiles at a rate of 2.04 and 1.44 cm/h, respectively. However, for disc plough (T₄) and ridger (T₂) profiles, basic infiltration rate was reached after 40 and 45 minutes, respectively. Disc plough has the greatest basic infiltration rate (3.24 cm/h), followed by ridger (2.404 cm/h), offset disc harrow and chisel plough (2.04 cm/h), and finally no-till (1.44 cm/h).

In the second season, ridger (T₂) and disc plough (T₄) also recorded the greatest infiltration rate, with the former slightly superior (22.44 vs. 21.72 cm/h), whereas no-till (T₅) again reported the least value (11.30 cm/h). The highest drop in infiltration rate, which was reported 10 minutes after the start of the process, was observed in disc plough profiles (9.48 cm/h), followed by the ridger (11.16 cm/h), offset
disc harrow (5.88 cm/h), disc plough (6.36 cm/h) and finally no-till profile (6.24 cm/h).

Fig. 4.3a
Fig. 4.3b
Basic infiltration rate (cm/h) was reached 35 minutes after the start of the process in disc plough (T₄) and no-till (T₅) profiles (3.00 and 1.44 cm/h, respectively). Forty minutes were needed for basic infiltration to be reached in the remaining tillage profiles. As in the 1st season, maximum and minimum basic infiltration rates were reported for disc plough (T₄) profiles (3.00 cm/h) and no-till (T₅) profiles (1.44 cm/h) profiles, respectively.

It is worth-mentioning that, in both seasons, infiltration process was monitored for 90 minutes to detect any changes in infiltration.

4.2 Machine performance

A group of physical parameters that were assessed during the three seasons were shown in Table 4.4a. They include; ploughing speed (km/h), ploughing width and depth (m), field efficiency (%), field capacity (ha/h), volumetric fuel consumption (l/hr and l/ha), and drive wheel slippage (%). Another group of parameters, which include draft-related parameters [total draft (kW)], unit draft (N/cm²) and drawbar power (kW) were taken only once and displayed in Table 4.4b.

From Table 4.4a, it is evident that, except for ridger plough (T₂), all other tillage machines were comparable in terms of their field efficiency (%). Average values were 81.0, 84.0 and 81.0% for offset disc harrow (T₁), chisel plough (T₃), and disc plough (T₄), respectively, compared to 74.0% for ridger plough (T₂).
Table 4.4a
Table 4.4b
Offset disc harrow (T₁) gave the best performance in terms of field capacity (ha/h) throughout the three seasons (0.71 ha/h), followed by ridger (T₂) plough (0.63 ha/h). Disc plough recorded the least performance regarding this parameter (0.26 ha/h).

Maximum fuel consumption on per hour (l/h) and per hectare (l/ha) basis was reported by disc plough (T₄) throughout the three seasons (3.92 l/h and 11.87 l/ha), followed by ridger (T₂) plough (3.41 l/h and 4.89 l/ha). Offset disc harrow consumed the least amount of fuel on per hour basis, followed closely by chisel plough (T₃). They averaged 1.70 and 2.23 l/h, respectively. However, on per hectare basis, chisel plough (T₃) averaged the least fuel consumption than offset (3.59 vs. 3.47 l/ha).

As far as machine performance, expressed in terms of drive wheel slippage (%) was concerned, chisel plough (T₃) maintained the highest values throughout the course of this study. It averaged 17.83% drive wheel slippage of power unit over all seasons. Disc plough (T₄) recorded (17.33%), followed by ridger plough (T₂) (16.02%), and finally the offset disc harrow (T₁) which averaged 15.60%, over all seasons. Moreover, it is worth-mentioning that, values of drive wheel slippage (%) obtained from the first season tests were comparatively higher, and chisel plough (T₃) also recorded the maximum value which amounted to 24.08%.
With regard to the prescribed draft-related parameters (Table 4.4b), disc plough (T4) recorded the highest draft requirements in terms of total draft (11.00 kN) as well as unit draft (6.11 N/cm²). These values amounted to two folds, and 2.48 fold the averages of the remaining implements (5.17 kN and 2.46 N/cm²), respectively. The least total and unit draft requirements were reported for ridger plough (4.50 kN and 0.96 N/cm², respectively).

Drawbar power (kW) requirements on the other hand were also greater for disc plough (13.60 kW) which was approximately twice the average of the remaining tillage implements (6.38 kW).

**4.3 Effect of tillage methods (T), water regime (W, %ETc), method of sowing (S), and their interactions on growth components of wheat**

Growth components comprised plant population at emergence and at harvest (plants/m²), plant height (at 3-weeks intervals from sowing, cm), leaf area index (LAI), leaf turgidity (assessed in the 1st and 2nd seasons only, %), and number of effective tillers (or heads) on per plant and square meter (m²) basis.

The effects of the prementioned factors on growth components were summarized in Tables (4.5a - 4.5f), as well as in Appendices B (Tables 1-3).
Table 4.5a
Table 4.5b
Table 4.5c
Table 4.5e
Table 4.5f
4.3.1 Effects on plant population (plants/m²)

4.3.1.1 Plant population at emergence

There was no significant (P < 0.05) effects on plant population at full emergence as due to any of the factors previously stated throughout the three seasons of study.

4.3.1.2 Plant population at harvest

Significant (P < 0.05) effects on plant population at harvest as due to tillage methods, water amounts (ETc%), and method of sowing were reported in all seasons as reviewed in Table (4.5a - 4.5f).

Except for no-till treatment (T₅), all other tillage methods were statistically similar in the 1st and 3rd season (Tables 4.5a and 4.5e). However, in the 2nd season disc plough (T₄) was significantly (P < 0.05) superior (325.7 plants/m²), whereas both no-till (T₅) and ridger (T₂) treatments recorded the least, but statistically similar values which amounted to 300.9 and 304.1 plants per m², respectively.

From Tables (4.5b, 4.5d and 4.5f) the least water amount (60% ETₐ) resulted in significantly (P < 0.05) lower populations at harvest, whereas maximum values were obtained when full (100% ETₐ); and full or medium (80% ETₐ) water regimes were adopted in the 1st and 3rd seasons; and in the 2nd season, respectively. Maximum numerical population value was 339.8 plants/m² averaged over all seasons, which was obtained under full irrigation water regime.
Plant population obtained from flat sowing was significantly (P < 0.05) superior to ridge planting in all seasons. Maximum plant population at harvest (334.9 plants/m²) was reported in the 1st season, compared to the season average, which amounted to 328.8 plants/m².

Interaction effect between water regime (W) and method of sowing (S) revealed that, 100% ETc water regime gave maximum plant population at harvest in the 1st and 2nd seasons, almost irrespective to seedbed type (Table 4.6). However, 60% ETc x ridge planting was the most significantly (P < 0.05) inferior combination in both seasons.

4.3.2 Effects on plant height (cm)

4.3.2.1 Plant height, 6 weeks after sowing

Results relating this parameter to the prescribed main factors are shown in Tables (4.5a - 4.5f). Plant height, 6 WAS (weeks after sowing) was found to be significantly (P < 0.05) affected by tillage methods (T) and water amounts (W, % ETc) in all seasons, as well as method of sowing (S) in the 3rd season only.

From Tables (4.5a, 4.5c and 4.5e), it is evident that no-till (T3) was significantly inferior to all other tillage methods in all seasons, averaging 21.96 cm. The other tillage treatments were statistically similar and superior in the 1st and 2nd seasons, except for disc plough (T4) in the 2nd season when it ranks the 2nd. Maximum seasonal averages were 27.56 and 20.61 cm, respectively. In the 3rd season, disc plough (T4) was significantly superior (26.51 cm) followed by chisel and ridger ploughs.

Table 4.6
From Tables (4.5b, 4.5d and 4.5f), maximum plant height was obtained from 100% ET<sub>c</sub> water regime in the 1<sup>st</sup> season (27.52 cm), and 100% - or 80% ET<sub>c</sub> regime in the 2<sup>nd</sup> (28.88 cm) and the 3<sup>rd</sup> (25.73 cm) seasons, respectively. Restricted water amount (60% ET<sub>c</sub>) resulted in shorter plants in all seasons. Maximum and minimum heights were 27.63 and 24.11 cm averaged over all seasons, respectively.

Effect of method of sowing, which was witnessed in the 3rd season only, resulted in significant (P < 0.05) superiority of flat beds (25.32 cm) compared to ridge planting (24.14 cm).

Interaction between water amount (W) and method of sowing (S) revealed that plant height was maximized when 100% ET<sub>c</sub> water amount was adopted with ridge planting (24.14 cm), whereas shorter plants were obtained under restricted watering (60% ET<sub>c</sub>), averaging 21.12 cm.

**4.3.2.2 Plant height, 9 weeks after sowing**

Referring to Tables (4.5a - 4.5f), plant height 9 WAS was significantly (P < 0.05) affected by both tillage methods (T) and water regime (W, % ET<sub>c</sub>) in all seasons, and by method of sowing in the 3<sup>rd</sup> season only.

From Tables (4.5a, 4.5c and 4.5e), except for no-till (T<sub>3</sub>) all tillage treatments were statistically similar and superior in all seasons, averaging 52.0 cm over all seasons. No-till was inferior and averaging only 40.63 cm.

From Tables (4.5b, 4.5d and 4.5f), application of 60% ET<sub>c</sub> irrigation water resulted in significantly shorter plants compared to
100% - and 80% ETc water amounts which were statistically similar in producing taller plants of average height that amounts to 51.97 cm, compared to 44.04 cm. Plant heights, 9 WAS were found to be significantly (P < 0.05) affected by method of sowing such that, ridge planting resulted in taller plants (47.03 cm) compared to flat sowing (45.37 cm), in the 3rd season.

4.3.2.3 Plant height, 12 weeks after sowing

Results pertaining to this parameter in the three seasons of study are shown in Tables (4.5a - 4.5f). Plant height, 12 WAS was significantly (P < 0.05) affected by tillage methods (T), water regimes (W, % ETc) and method of sowing (S) in all seasons except for the latter factor in the 3rd season.

From Tables (4.5a, 4.5c and 4.5e), it is evident that no-till treatment (T5) was significantly inferior to all tillage methods in all seasons. However, chisel plough (T3), and disc plough (T4) resulted in the tallest plants (68.48 vs. 69.17 cm), followed by ridger (T2) and disc plough (T4); and ridger (T2) and chisel plough (T3), which were statistically similar in the 1st and in the 3rd seasons, respectively.

From Tables (4.5b, 4.5d and 4.5f), results pertaining to the effects of water amounts (ETc %) on this parameter were identical in all seasons. Full (100% ETc) and medium (80% ETc) water regimes were statistically (P < 0.05) similar and superior to the smaller water regime (60% ETc) in all seasons. Maximum and minimum over-season averages were 69.80 and 61.60 cm, respectively.
Ridge planting on the other hand, was statistically ($P < 0.05$) superior to flat sowing in the 1st and 2nd seasons. Corresponding values were 69.07 and 66.18 cm averaged over all seasons, respectively.

4.3.2.4 Plant height at harvest

Plant height (cm) at harvest was significantly ($P < 0.05$) affected by tillage methods ($T$), water regimes ($W$, $ET_c\%$), and method of sowing ($S$) throughout the course of research. The general trend is shown in Figs. (4.4a, 4.4b and 4.4c).

As shown in Tables (4.5a, 4.5c and 4.5e), effects of tillage methods ($T$) on plant height at harvest were almost identical in all seasons. No-till treatment ($T_5$) was significantly ($P < 0.05$) inferior in all seasons, and averaging 66.02 cm. On the other hand, maximum height of plant at harvest was recorded by offset disc harrow ($T_1$) and ridger ($T_2$); offset, ridger and chisel plough ($T_3$); and disc plough ($T_4$) in the 1st, 2nd and 3rd seasons, respectively. Corresponding averages were 73.58; 70.75 and 70.66 cm, respectively.

From Tables (4.5b, 4.5d and 4.5f), it is evident that, obtainable results pertaining to the effect of water amounts ($ET_c\%$) on this parameter were also comparable for all seasons. Significantly ($P < 0.05$) taller plants were obtained in profiles receiving non-restricted watering conditions (100% $ET_c$) in the 1st season (75.18 cm); and 100% - or 80% $ET_c$ in the 2nd (averaging 69.92 cm) and the 3rd (averaging 70.03 cm) seasons.
Fig. 4.4a
Fig. 4.4c
Ridge planting (S₂) was found to be significantly (P < 0.05) superior to flat sowing (S₁) in terms of plant height at harvest throughout the three seasons of study. Corresponding values were 70.25 and 66.80 cm, averaged over all seasons, respectively.

4.3.3 Effect on leaf area index (LAI)

As shown in Tables (4.5a - 4.5f) and Figs. (4.5a, 4.5b and 4.5c), LAI was significantly (P < 0.05) affected by all the prescribed factors in all seasons except for tillage treatments (T) in the 2nd season, and method of sowing (S) in the 3rd. Interaction effect (T x W) was also reported in all seasons at the same level of significance.

Tables (4.5a and 4.5e) revealed that no-till (T₅) resulted in the least value of LAI (1.54) in the 1st and 3rd seasons, respectively. Maximum average LAI (1.84) was obtained in the 3rd season from chisel (T₃) and disc (T₄) plough treatments, which were statistically similar. In the 1st season, offset disc harrow (T₁), ridger (T₂), and chisel (T₃) were statistically similar and recorded the maximum LAI (averaged 1.74).

From Tables (4.5b, 4.5d and 4.5f), restricted watering regimes (60% ETₜ) resulted in significantly (P < 0.05) smaller LAI values, whereas full water regimes (100% ETₜ) and medium regimes (80% ETₜ) were statistically similar except in the 2nd season, and produced the highest LAI values. Maximum and minimum values were 1.80 and 1.36, averaged over all seasons, respectively.
Fig. 4.5a
Fig. 4.5b
Fig. 4.5c
Flat sowing on the other hand, resulted in significantly ($P < 0.05$) higher LAI values compared to ridge sowing, averaging 1.63 and 1.53 in the 1$^{st}$ and 2$^{nd}$ seasons, respectively.

A significant ($P < 0.05$) interaction effect between tillage (T) and water amounts (W, % ET$_c$) was reported in all seasons as shown in Table 4.7. Chisel plough (T3) x full watering regime (100% ET$_c$) was significantly superior to all other combinations in the 1$^{st}$ season (2.06), followed by offset disc harrow (T1), ridger (T2), and disc plough (T4) at the same watering regime as a statistically similar group which averaged 1.92. The least LAI values were reported by the 60% ET$_c$ water regime irrespective to tillage method. In the 2$^{nd}$ season, profiles receiving 100% ET$_c$ or 80% ET$_c$ of irrigation water produced maximum LAI irrespective to tillage method. They were statistically similar and averaged 1.62. It is worth mentioning that disc plough x 60% ET$_c$ combination produced the least LAI in both the 1$^{st}$ and 2$^{nd}$ seasons (averaged 1.12).

In the 3$^{rd}$ season, maximum LAI was 2.05 which was obtained from profiles receiving disc plough x 80% ET$_c$ combination followed by disc plough x 100% ET$_c$ (2.01), chisel plough x 100% - or 80% ET$_c$ (averaging 1.92), and ridger x 100% ET$_c$ (1.89), which were statistically similar at 5% level of significance. Ridger x 60% ET$_c$ gave the least LAI value of 1.35.
Table 7
4.3.4 Effect on leaf turgidity (LT, %)

As shown in Tables (4.5a - 4.5d), this parameter was assessed in the 1st and 2nd seasons only.

Effect of water amount (ETc %) on LT was significant (P < 0.05) in both seasons (Tables 4.5b and 4.5d). LT (%) increased with increased water amount (ETc %) in both seasons.

Full water regime (100% ETc) and medium regime (80% ETc) were statistically similar and produced the maximum LT of 46.16%, whereas the smaller water amount (60% ETc) gave the least LT of 35.25%, averaged over both seasons.

LT (%) was affected significantly (P < 0.05) by method of sowing where flat sowing out yielded ridge planting in the 1st season.

4.3.5 Effect on number of tillers

4.3.5.1 Number of tillers/plant

This parameter considered the effective or productive number of tillers, which was synonymous with number of heads.

With aid of Figs. (4.6a, 4.6b and 4.6c), the number of effective tillers (heads)/plant was significantly (P < 0.05) affected by water amounts (ETc %) and method of sowing in all seasons, and by tillage methods, and its interaction with water amount (T x W) in the 1st and 2nd seasons only.

Tables (4.5a and 4.5c) highlights the effect of tillage (T) where no-till treatment (T5) gave the least statistical (P < 0.05) number of
Fig. 4.6a
Fig. 4.6b
Fig. 4.6c
heads/plant (1.01), whereas all other tillage treatments were statistically similar to provide the highest value of 1.57 heads/plant averaged over all the remaining treatments and seasons.

Tables (4.5b, 4.5d and 4.5f) show that, the highest value of this parameter was obtained in profiles that received 100% ET<sub>c</sub> water regimes to average 1.72 effective tillers per plant, whereas the least value (averaged 1.03 heads/plant) over all seasons, was obtained when irrigating with restricted regime (60% ET<sub>c</sub>).

Method of sowing significantly (P < 0.05) affected this parameter such that, higher number of heads/plant (1.58) was recorded for flat sowing in all seasons, compared to only 1.09 heads for ridge sowing, averaged for all seasons.

Interaction effect of (T x W) was reported for the 1<sup>st</sup> and 2<sup>nd</sup> seasons, and displayed in Table 4.8a. Number of effective tillers (heads/plant) was greater with ridger (T<sub>2</sub>) x 100% ET<sub>c</sub> in the 1<sup>st</sup> season (1.09), as well as 100% ET<sub>c</sub> x chisel (1.09), and disc plough (1.86) in the 2<sup>nd</sup> season. No-till (T5) x 60% ET<sub>c</sub> was inferior in terms of this parameter in all seasons, and averaged only 0.56 heads/plant.

### 4.3.5.2 Number of tillers/m<sup>2</sup>

Results pertaining to the effect on number of effective or productive tillers or number of heads/m<sup>2</sup>, due to the experimental treatments are shown in Tables (4.5a - 4.5f).

Significant (P < 0.05) effects of tillage (T), water amounts (W, ET<sub>c</sub> %) and method of sowing (S) on this parameter were reported for
Table 4.8a
all seasons. From Tables (4.5a, 4.5c and 4.5e), it is obvious that the observable results regarding the effect of tillage on this parameter were comparable in all seasons. No-till (T₅) gave the least number of effective tillers (320.3 heads/m²) compared to all other tillage treatments which were almost similar in all seasons and averaging 500.4 heads/m².

Tables (4.5b, 4.5d and 4.5f) show that both 100% - and 80% ETᵩ water regimes were similar in producing the maximum number of heads per m² (averaging 553.4). The 60% ETᵩ water regime produced the lowest number of effective tillers/m² in both seasons, and averaged 454.9 heads.

Significant (P < 0.05) effects on this parameter were also reported to be due to method of sowing in all seasons. Flat sowing was superior and produced average number of heads/m² which amounted to 526.6, 547.2 and 363.4, compared to 505.9, 502.3 and 333.4 heads for ridge sowing in the successive seasons, respectively.

Interaction effects were observed between water amount (W, ETᵩ %) and method of sowing (S) in the 1ˢᵗ and 3ʳᵈ seasons (Table 4.8b). Flat sowing was superior when combined with both 100% and 80% ETᵩ water amounts, whereas the remaining water regime (60% ETᵩ) gave the least number of heads/m² irrespective of method of sowing. Maximum and minimum averages were 467.7 and 398.1 heads/m², respectively.
Table 4.8b
In contrast to the 3rd season, interaction results obtained for both 100% and 80% ETc water regimes in the 1st season, were significantly (P < 0.05) greater irrespective of method of sowing.

Results pertaining to the effects of the prementioned factors on yield and its components were summarized in Tables (4.9a - 4.9f) and Appendix B (Tables 4-6).

Yield components include number of fertile spikelets/spike, number of seeds/spike, weight of spike (g), number of seeds/plant, weight of seeds/plant (g), 1000-grains weight (g), and harvest index (HI, %), in addition to total grain yield (t/ha).

4.4.1 Effect on number of fertile spikelets/spike

Tillage methods (T) significantly (P < 0.05) affected this parameter in the 2nd and 3rd seasons, whereas the effects attributed to water amounts (W, ETc %) were witnessed in all seasons. Interaction effect (T x W), on the other hand was reported in the 2nd and 3rd seasons.

From Table 4.9c, it is obvious that disc plough (T4) and ridger (T2) out yielded other tillage treatments in the 2nd season, and averaged 13.65 spikelets/spike. In the 3rd season (Table 4.9e), disc plough (T4) and chisel plough (T3) were significantly (P < 0.05)
Table 4.9b
Table 4.9c
Table 4.9d
Table 4.9e
Table 4.9f
superior and averaged 14.27 spikelets/spike. Chisel plough, and no-till (T5) recorded the least values of 12.07 and 13.09 spikelets/spike in both seasons, respectively.

Tables (4.9b, 4.9d and 4.9f) show that, while the 60% ETc water regime gave the least number of spikelets/spike (11.71), the 100% and 80% ETc regimes together reported the higher values (13.69) of the parameter, averaged over all seasons.

From Table 4.10, it is evident that disc plough (T4) x (W3), 60% ETc and chisel plough (T3) x W3 in the 2nd season, as well as no-till (T5) x W3 in the 3rd season were significantly (P < 0.05) inferior in terms of number of fertile spikelets/spike. They averaged 10.27, 10.62 and 12.28 spikelets/spike, respectively. On the other hand, maximum values of the parameter were reported by ridger (T2) x (W1), 100% ETc in the 2nd season (15.35 spikelets/spike), and chisel plough (T3) x W1 (14.83) and disc plough (T4) x W1 (14.75 spikelets/spike) in the 3rd season.

4.4.2 Effects on number of seeds/spike

Data pertaining to the effect of tillage, water amount and method of sowing on number of seeds/spike are shown in Tables (4.9a - 4.9f). Both tillage methods (T) and water amounts (W) have significantly (P < 0.05) affected this parameter in all seasons.

No-till treatment (T5) gave the lowest number of seeds/spike (averaged 24.27) in all seasons. Ridger (T2) was found superior in the 1st season (Table 4.9a), while chisel plough (T3) was the best in the 2nd and
3rd seasons (averaged 28.31 and 28.23 seeds/spike), as displayed in Tables (4.9c and 4.9e), respectively.

Table 4.10
From Tables (4.9b, 4.9d and 4.9f), the effect of water amount on this parameter was prominent. The 60% ET<sub>c</sub> water regime was significantly (P < 0.05) inferior in all seasons, whereas the 100% ET<sub>c</sub> regime was the best in the 1<sup>st</sup> and 2<sup>nd</sup> season, but statistically similar to the 80% ET<sub>c</sub> regime in the 3<sup>rd</sup>. Maximum and minimum values were 28.67 and 24.02 seeds/spike, averaged over all seasons, respectively.

4.4.3 Effects on weight of spike (g)

Weight of spike (g) was significantly (P < 0.05) affected by water amount (W, ET<sub>c</sub> %) in the three seasons (Tables 4.9b, 4.9d and 4.9f), and by tillage treatments (T) in the 1<sup>st</sup> and 2<sup>nd</sup> seasons (Tables 4.9a and 4.9c), as well as by method of sowing (S) in the 1<sup>st</sup> and 3<sup>rd</sup> seasons. Relevant data on this regard are shown in Figs. (4.7a, 4.7b and 4.7c).

As shown in Table (4.9a), results of the 1<sup>st</sup> season revealed that disc plough (T<sub>4</sub>) significantly (P < 0.05) out yielded all tillage treatments which were statistically similar and averaged 1.90 g. In the 2<sup>nd</sup> season (Table 4.9c), both offset disc harrow (T<sub>1</sub>) and ridger (T<sub>2</sub>) were statistically similar and superior in terms of weight of spike, and averaged 2.08 g. No-till (T<sub>5</sub>) was significantly inferior in both seasons and averaged only 1.44 g of spike weight.

Table 4.9b confirms at 5% level of significance that profiles which received 60% ET<sub>c</sub> water amounts, produced the lowest weight of spike in all seasons (averaged 1.47 g), whereas the 100% ET<sub>c</sub> water regime gave the greatest values of spike weight (2.11 g) in the 1<sup>st</sup> season, but together with the 80% ET<sub>c</sub> regime in the 2<sup>nd</sup> and 3<sup>rd</sup> seasons (Tables 4.9d and 4.9f, respectively).

Fig. 4.7a
Fig. 4.7b
Fig. 4.7c
Flat sowing was superior to ridge sowing in the 1<sup>st</sup> and 3<sup>rd</sup> seasons where it averaged 2.40 and 1.71g compared to 1.74 and 1.56g, respectively.

4.4.4 Effects on number of seeds/plant

Results obtained from three successive seasons concerning the effect of tillage, water amount and method of sowing on this parameter are displayed in Figs. (4.8a, 4.8b and 4.8c). Tabulated results showed that tillage methods (T) and water regimes (W, ET<sub>c</sub> %) have significantly (P < 0.05) affected the number of grains per plant in all seasons.

Ridger (T<sub>2</sub>) produced the highest number of seeds/plant (averaged 47.65) in the 1<sup>st</sup> and 2<sup>nd</sup> seasons (Tables 4.9a and 4.9c), followed by offset disc harrow (T<sub>1</sub>). In the 3<sup>rd</sup> season (Table 4.9e), disc plough (T<sub>4</sub>) out yielded all tillage treatments (31.46 seeds/plant), followed by chisel plough (T<sub>3</sub>). On the other hand, no-till (T<sub>5</sub>) produced the smallest number of seeds/plant in all seasons, which averaged 26.26 seeds.

From Tables (4.9b, 4.9d and 4.9f), it is evident that, 100% ET<sub>c</sub> water amount has produced the highest number of seeds/plant, whereas the restricted water regime (60% ET<sub>c</sub>) gave the lowest values, in all seasons. The medium water regime (80% ET<sub>c</sub>) was found statistically similar to the 100% ET<sub>c</sub> regime in producing superior results. Maximum
and minimum averages were 40.80 and 33.49 seeds/plant, averaged over all seasons, respectively.
Fig. 4.8a
Fig. 4.8b
Fig. 4.8c
4.4.5 Effects on weight of seeds/plant (g)

Significant (P < 0.05) effects on this parameter as due to tillage (T) and water amount (W, ETc %) were reported in all seasons.

No-till (T5) reported the least significant weight of seeds/plant in all seasons (averaged 1.49 g), whereas offset disc harrow (T1), ridger (T2) and disc plough (T4) have together produced the greatest values in the 1st season (average of 1.83 g), offset and ridger in the 2nd season (average of 1.89 g), and all tillage methods other than no-till (T5) in the 3rd season (average of 1.64 g), as shown in Tables (4.9a, 4.9c and 4.9e).

By referring to Tables (4.9b and 4.9d), it is obvious that the least water regime (60% ETc) produced the least significant weight of seeds per plant (1.56 and 1.43 g), compared to the two other regimes which were statistically similar in producing the largest values of this parameter (averaged 1.83 and 1.84 g), in the 1st and 2nd seasons, respectively.

4.4.6 Effects on 1000-grains weight (g)

As shown in Tables (4.9a - 4.9f), tillage methods and water amounts significantly (P < 0.05) affected the 1000-grains weight (g).

The effect of tillage method (T) was witnessed in the 1st and 2nd seasons (Tables 4.9a and 4.9c) where no-till (T5) gave the least 1000-grains weight (averaged 26.96 g), compared to all other tillage methods which averaged 37.75 g, over both seasons.
Water regimes (ETc, %) have significantly affected this parameter in all seasons (Tables 4.9b, 4.9d and 4.9f). Maximum weights of 1000-grains were obtained when either 100% ETc or 80% ETc water regimes were adopted in all seasons. Maximum and minimum averages, over all seasons were 34.97 and 30.17 g, respectively.

### 4.4.7 Effects on total grain yield (t/ha)

Results pertaining to the effect of tillage methods (T), water amounts (W, ETc %), and method of sowing (S) are presented in Figs. (4.9a, 4.9b and 4.9c). Detailed results are shown in Tables (4.9a - 4.9f).

Tillage methods and water regimes have significantly (P < 0.05) affected grain yield (t/ha) in all seasons (Tables 4.9a, 4.9c and 4.9e), whereas the effects attributed to method of sowing (S) were reported in the 1st and 2nd seasons, at the same level of significance.

It is evident that no-till (T5) was significantly (P < 0.05) inferior in terms of grain yield (t/ha) in all the three seasons of study, and averaged 1.91 t/ha. With respect to maximum grain yields, both ridger (T2) and offset showed significant superiority in the 1st and 2nd season, and averaged 2.94 t/ha. Chisel (T3) and disc (T4) ploughs ranked the 3rd and 4th in both seasons and averaged 2.69 and 2.58 t/ha, respectively. In the 3rd season, all tillage methods other than no-till (T5) were statistically similar and superior on per hectare yield basis (averaged 1.62 t/ha).

Fig. 4.9a
Fig. 4.9b
Fig. 4.9c
Tables (4.9b, 4.9d and 4.9f) show the effects of water regimes (ETc %) on grain yield (t/ha). It is evident that, throughout the three seasons, application of full (100%) or medium (80%) amounts of irrigation water in terms of ETc % produced the highest grain yields of wheat which were statistically similar, but superior to the 60% ETc watering regime at 5% level of significance. Grain yields (t/ha) averaged over all seasons were 2.90, 2.73 and 2.03 t/ha for the corresponding watering regimes, respectively.

Flat sowing (S1) produced grain yields that were significantly (P < 0.05) greater than those obtained from ridge sowing (S2) in the 1st and 2nd seasons. Corresponding values were 2.62 and 2.43 t/ha, as well as 2.85 and 2.54 t/ha, respectively.

4.4.8 Effects on harvest index (H.I, %)

Results pertaining to this parameter as due to the effects of tillage, water amount, and method of sowing are shown in Figs. (4.10a, 4.10b and 4.10c).

Tillage methods (T) significantly (P < 0.05) affected harvest index (%) in all seasons (Tables 4.9a, 4.9c and 4.9e). In the 1st season, offset disc harrow (T1) out yielded all tillage treatments (46.89%), followed by both ridger (T2) and chisel (T3), which averaged 45.18%. In the 3rd season, both chisel and disc plough (T4) were superior and averaged 35.28%, followed by ridger (31.33%). In the 2nd season, all tillage methods, except no-till (T5) were statistically similar in producing the maximum HI values, and averaged 44.73%. The least values of HI were recorded by no-till (T5) in all seasons (averaged 29.61%).

Fig. 4.10a
Fig. 4.10b
Fig. 4.10c
From Tables (4.9b, 4.9d and 4.9f), it is evident that in all seasons, both 100% and 80% ETc watering regimes produced the maximum HI (%). They averaged 40.64%, compared to 35.19% which was reported by the 60% ETc regime.

Flat seedbeds on the other hand, were significantly (P < 0.05) superior to ridged beds in terms of HI (%) in the 1st and 2nd seasons. Corresponding values were 42.58 and 41.40%; and 42.40 and 41.00%, respectively. In the 3rd season, although method of sowing had no significant effect on HI (%), but fat sowing was numerically superior.

4.5 Water use efficiency (WUE, kg/m³)

As shown in Fig. 4.11 as well as table 4.11, it is evident that WUE (kg/m³) was lower in treatments that received 100% ETc watering regime in all seasons (average of 0.36 kg/m³). The greatest values for WUE, on the other hand were reported in connection with 80% ETc watering regime (averaged 0.43 kg/m³). In other words, when descending from 100%, or ascending from 60% water amounts in term of ETc %, WUE tend to increase sharply, as a general trend.
Fig. 4.11
5.1 Status of soil moisture content (SMC)

Soil moisture content (SMC) was assessed on pre-tillage and post-harvest (residual) basis as shown in Fig. 4.1 and Tables (4.1a, 4.1b and 4.1c), respectively. Pre-tillage Soil moisture content (SMC) was increasing with soil depth in both seasons. Historically, the experimental site was a sorghum-stubbled fallow which was expected to improve the infiltration capacity of the soil during the succeeding rainy season. On the other hand, excessive evaporation from soil surface and its adjacent layers tend to lend extra opportunity for soil moisture to accumulate underneath.

Comparatively much post-harvest residual soil moisture content was reported in flat beds that received 100% ETc irrigation levels. This was expected since richer irrigation streams permit excessive percolation of irrigation water down the profile and even beyond rootzone with elapsing time, particularly in fine-textured soils. Farah et al. (1995) pointed out similar observations. Moreover, 50 – 60% of water uptake of wheat was confined to the upper 0.30 m – depth soil layer, which represents the effective rootzone of common wheat cultivars. Beyond this depth, moisture pockets might not be fairly accessible and remain as potential available soil moisture reserves after harvest. Such generalization was stated by Doorenbos and Kassam (1986), Salih et al. (1992) and Raemakers (2002).
The superiority of ridger and disc plough systems in conserving high residual soil moisture might be attributed to the deeper action of the former on one hand, and profuse rooting density, established in a shallow, well-disturbed profile of the latter on the other hand. Deep ploughing tends to induce direct water percolation, while profuse rooting mass tends to initiate improved macroporosity with time, since soil samples containing greater root masses were usually associated with greater pore volumes and would finally induce deeper percolation of water. In absence of tillage and machinery travel, pore continuity will be maintained and in turn water percolation will be induced. These conclusions were drawn by Culley et al. (1987), Perrier and Salkini (1987), Edwards et al. (1988), Meek et al. (1990), Bukhari et al. (1992), Mahboubi et al. (1993), and Sabir et al. (1996).

5.2 Effect of tillage methods on bulk density (g/cm$^3$) and porosity (%)

As shown in Tables (4.2a and 4.2b) as well as in Fig. 4.3, all bulk densities (g/cm$^3$) were within the range of 0.90 to 1.80 g/cm$^3$, a range described by Chi et al. (1993) as being usual for agricultural soils. However, statistically no significant (P < 0.05) differences in bulk density and porosity, at the prescribed soil depths were detected to be due to the different tillage systems even at its generalized levels as plough-till or no-till systems. Similar findings were reported by Williams (1986), Meek et al. (1989, 1990), Erbach et al. (1992), Meek et al. (1992), and Mahboubi et al. (1993), who generally attributed their
findings to the contradicting effect of tillage when the attained improvements in soil bulk density and porosity might be offset by wheel induced compaction resulting from static and dynamic weights of machinery, mostly from the first pass. On the other hand, Radcliffe et al. (1988) described these results as inevitable when mulch cover was un-sustained and managed on no-till plots.

Improvements in bulk density resulted from plough-till in the second season, and from chisel plough system in the 1st season were numerically lower than those of no-till treatments. This was in line with the findings of Potter et al. (1988), Acevedo et al. (1990), Harris et al. (1991), Meek et al. (1992), and Kumar (2000). In contrast, ridger, offset disc harrow, and disc plough systems produced bulk densities that were numerically greater than those obtained from no-till plots. This might be attributed to spatial variability as reported by Kumar (2000), or to the contradicting effect resulting from plough weight as stated previously.

The greater bulk densities and the lower porosity incurred at the top layer (0 – 0.40 m) compared to sublayers, in no-till plots was a characteristic feature of the system as described by Hill (1987), Raines and Bicki (1993), Ray and Gupta (2001), Kumar and Pandey (2002), and Sabir and Mrabet (2002), particularly in the short run. However, with respect to plough-till, ridger and chisel plough systems have generally resulted in reduced bulk densities at deeper horizons than at top surface. This might be attributed to its characteristic design features in disturbing deeper layers. Similar conclusions were drawn by Abdul Razzaq and Sabir (1992), Bukhari et al. (1992), Ahmed and Haffar (1993), and Sabir et al. (1996).
Disc plough regime produced the least bulk density and highest porosity values compared to other plough-till treatments in both seasons. This might be due to its unique disturbance effect in producing much pores at shallow depths, and hence improves macropore system. This was in agreement with the findings of Ankeny et al. (1995), and Ray and Gupta (2001). Bulk density was expected to deteriorate at medium layer (0.20 – 0.40 m) most likely due to the static and dynamic weights’ effect of the plough in producing plough soles just beneath its working zone. Similar conclusions were confirmed by Perrier and Salkini (1987), Bukhari et al. (1992), and Sabir et al. (1996).

5.3 Effect of tillage methods on infiltration characteristics

Data pertaining to this variable were shown in Figs. (4.3a and 4.3b). The temporally greater initial infiltration rates recorded by ridger and disc plough treatments in both seasons might be attributed to the deep ploughing effect of the former, as well as to the excessive surface disturbance of the latter. However, in case of chisel plough treatments, although much pores were expected to be obtained, but they might be blocked with finer clay particles with time when water was applied for assessing infiltration characteristics. Spatially variable physical conditions of soil surface and the adjoining layers might be another reason. Similar observations were stated by Michael (1978), Packer et al. (1984), Perrier and Salkini
Offset disc harrow profiles did not induce active initial infiltration mostly due to its greater bulk densities and impeded porosity as stated in section 5.2.

No-till profiles recorded the least initial infiltration in both seasons. This was expected as explained in section 5.2. In fact, more time is needed for macropore system to develop in order to offset the effect of compaction and greater bulk densities. Moreover, the absence of mulch cover also tends to impede biological activity and macropore continuity as explained in section 5.2.

In both seasons, basic infiltration rate was reached earlier in chisel and no-till profiles, most likely due to the conditions stated previously, which generally imply blocked macropores and impeded initial infiltration. Only half an hour is enough for basic infiltration rate to be reached in fine-textured, poorly drained soils, while up to six hours are a pre-requisite to suffice the process under the other extreme of profile characteristics as confirmed by Potter et al. (1988).

For ridge and disc plough profiles, steady-state infiltration rate was comparatively greater, and was slightly delayed. This might be due to the active initial infiltration rate, which would possibly induce lateral movement of water beyond the sphere of the infiltrometer, as well as deep percolation into a deeply ploughed profile. Sabir et al. (1996), and Moreno et al. (1997) reported similar conclusions when they recorded earlier basic infiltration rate in chisel and no-till profiles compared to
disc plough, and justified their findings on the basis of greater cumulative pore volume in favour of the latter plough. Offset disc harrow profile was almost comparable to disc plough in terms of infiltration characteristics despite its higher calculated bulk density. This might be due to spatial variability or improvements in macropore system from the previous farming system as stated earlier.

5.4 Machine performance
5.4.1 Field capacity (C, ha/h)

As shown in Table 4.4a, the least field capacity (ha/h) was recorded by disc plough. This was expected since the plough has the least effective ploughing width (w) at comparable ploughing speeds and depths, as well as maximum draft requirements (Table 4.4b) which reduces the effective ploughing speed, and consequently field capacity.

Offset disc harrow has the best field capacity records most likely due to the greater effective ploughing width and shallower depth as well as medium draft requirements.

Ridger and chisel ploughs, although they recorded the least total draft requirements, but however, they either posses the deepest ploughing depth, or comparatively a smaller effective width than offset disc harrow, which both tend to decrease field capacity. These findings were in agreement with those obtained by Patterson (1982), Mueller and
5.4.2 Field efficiency (e, %)

As shown in Table 4.4a, the ridger recorded the least field efficiency. This might be due to its comparatively deeper ploughing action in all seasons, which affects working pattern at farm level. Efficient field operations undertaken by disc plough might be attributed to reduced time losses and adjusted operating conditions. Generally, field efficiencies of offset disc harrow, chisel plough, and disc plough were almost comparable in fine-textured soils that are relatively firm. These findings were confirmed by Abdull Razzaq and Sabir (1992). Moreover, field efficiencies assessed on time-basis are generally influenced by operator skill in adjusting his operating pattern, as confirmed by Igbeka (1986).

5.4.3 Fuel consumption (l/h and l/ha)

Results pertaining to this parameter showed that maximum fuel consumption was recorded by disc plough on per time and per unit area basis (Table 4.4a). This was expected owing to the huge draft requirements as a prerequisite functional component to pull the greater static
and dynamic weight of the plough. The plough is basically
dependent upon these weights to perform its prescribed job.

On the other hand, although fuel consumption records from chisel plough, and offset disc harrow were almost comparable, the former consumed a slightly less amount of fuel, most likely due to its lower draft requirements as well as its lighter weight when compared to the latter. Similar results were stated by Bukhari and Baloch (1982), Michael et al. (1983), Bandy et al. (1986), Bowers (1986), Igbeka (1986), and Ahmed and Haffar (1993).

5.4.4 Drive wheel slippage (%)

It is evident that, all drive wheel slippage values displayed in Table 4.4a were below the top limit of 25% expressed at maximum loading and depth, as described by Pensson et al. (1986).

Drive wheel reduction of the second and third seasons were considerably lower compared to the first season. This might be attributed to smooth non-harsh working conditions as explored in form of improvements in some soil physical conditions on such type of soil as mentioned previously. The least slippage values were recorded by offset disc harrow and ridger, most likely due to higher ploughing speed (Table 4.4a) which did not permit enough time for the plough to penetrate into the soil, and/or medium static and dynamic loads that added to the stability and ballasting of the machine. Similar observations were highlighted by Singh and Rautaray (1982), and Shebi et al. (1988).
Higher slippage values were recorded by disc plough and chisel, most probably due to increased load transfer to the rear drive wheel of the tractor with increasing depth of work particularly under conditions when the ploughing speed and depth become erratic. Operator skill is the key factor that might alter values of this parameter at field level as confirmed by Baloch et al. (1993), Igbal et al. (1994), McKyes and Maswaure (1997), and Dahab and Mohamed (2002).
5.4.5 Draft requirements (kN)

Draft components [total (kN)], and unit (N/cm²), draft], as well as power requirements (kW) of disc plough were the highest among all other tillage implements tested (Table 4.4b). This result was justifiable owing to the characteristic working features of this plough, which depends on its greater static and dynamic weights. Therefore, extra draft and power inputs should be restored. Many workers agree with this statement, including Bashford et al. (1991), Shirin et al. (1993), Poje (1996), and McKyes and Maswaure (1997). On the other hand, draft requirements of the remaining implements were almost comparable. However, the ridger has comparatively smaller traction requirements, while the offset disc harrow has the greater draft, most probably due to the relatively higher static and dynamic weights of the latter.

Generally, fluctuations in ploughing depth and speed, which depend on field conditions and operator skill, may result in appreciable inconsistencies in the results. However, under ideal ploughing conditions, both offset disc harrow and chisel plough were expected to maintain draft and power requirements that are closer to disc plough. These conclusions and findings were reported by many workers as well as Shirin et al. (1993).
5.5 Effect of tillage methods, watering regimes, method of sowing, and their interactions on growth components of wheat

5.5.1 Effect on plant population (plants/m²)

5.5.1.1 Population at emergence

*All treatments were statistically similar in terms of population at full emergence* Tables (4.5a - 4.5f) most likely due to the high emergence % of seeds, as well as uniformity in seeding and watering.

5.5.1.2 Population at harvest

No-till was significantly inferior in managing final stand at harvest in all seasons (Tables 4.5a, 4.5c and 4.5e). The greater bulk density and compaction hazards associated with no-till systems in absence of mulch cover tended to induce stunted growth of plants and reduced stand population, due mainly to impeded rootzone environment. Similar remarks were stated by Maurya (1989), and Tareq (1996).

Significantly lower plant populations at harvest were obtained at plots which received 60% ETc irrigation regime throughout the seasons (Tables 4.5b, 4.5d and 4.5f). This might be attributed to poor tillering associated with scanty watering regimes, since tillering was very sensitive to water stress particularly at moisture deficits beyond 25% ETc. These findings were reported by Hussein *et al.* (1978), Moursi *et al.* (1979), and Moustafa *et al.* (1996) which confirmed the result that, plant populations associated with 100% - and 80% ETc were statistically
similar and superior when water requirements of 75% $E_{Tc}$ or more were guaranteed at tillering.

Flat sowing produced significantly greater population at harvest since ample space and light activated profuse tillering. Mahdi et al. (1998) confirmed this result when he recorded poor number of tillers with ridge sowing which reduced final yield. In contrast, Omer (1990) reported significant results in favour of ridge sowing in producing greater number of plants/m² (population) due to better control of both weeds and irrigation water. Taha (1990), and Dawelbeit and Babiker (1997) agreed with the latter worker.

5.5.2 Effect on plant height (cm)

Results pertaining to this parameter were shown in Tables (4.5a - 4.5f). Plant heights taken 3 weeks after sowing (WAS) were statistically similar. In fact, the newly established seedlings received similar amounts of water, while tillage effect needs more time to develop.

Plant height taken 6 WAS until harvest was found to be significantly affected by tillage. Throughout the development cycle of the crop, plants raised on no-till system basis were remarkably stunted due to impeded soil structure. More time is needed for macropore system to develop and offset the ill effects of no-till, provided that a well-managed mulch cover was sustained on the plots as explained earlier in this chapter. Plough-till treatments, on the other hand were almost statistically similar in producing taller stands due mainly to improved rootzone environment restored by tilling a fine-textured soil.
Similar observations were reported by Maurya (1989), Erbach et al. (1992), and Singh et al. (1998).

Effect of irrigation regime on plant height within the prescribed range of growth period showed that, taller plants were obtained when 100% - or 80% ET$_c$ watering regimes were adopted, while the 60% ET$_c$ regime produced significantly stunted plants (Table 4.5b, 4.5d and 4.5f). In fact, under ideal conditions, wheat plants were expected to attain maximum growth potentialities when irrigation water was approaching its full requirements, particularly from booting (flowering) to anthesis and through grain filling. This statement was confirmed by Doorenbos and Pruitt (1977), Hussein et al. (1978), Moursi et al. (1979), and Farah (1995).

Ridge planting was found to induce taller plants from 6 WAS till anthesis (9 WAS) in one season only. From anthesis onwards, ridge-planting effect dominated flat sowing till the end of the crop life cycle in two or more seasons. This might be due to the compensating effect of ridges in managing irrigation water and weeds as well as preventing crusting, particularly in treatments that received the least amount of water (60% ET$_c$). On the other hand, the smaller space allowed to plants tended to initiate vigorous upright growth for obtaining maximum light. Ridges were also efficient in reducing flooding hazards. These results were confirmed by Babiker and El Hassan (1990), Omer (1990), Satti (1990), and Dawelbeit and Babiker (1997).

5.5.3 Effect on leaf area index (LAI)
Referring to Tables (4.5a, 4.5c and 4.5e) LAI was found to be significantly inferior with no-till treatments in two seasons. In fact, this parameter depends entirely on canopy and population characteristics in a given area. No-till was reported earlier to provide little support in this regard. Plough-till treatments were almost identical in affecting this parameter, except for disc plough in one season most probably due to spatial compaction variations, or other relevant changes in soil physical characteristics. Similar justifications were stated by Meek et al. (1992).

The effect of water amount on this parameter was evident in all seasons (Tables 4.5b, 4.5d and 4.5f). Higher LAI values were associated with irrigation water amounts of 80% ET$_c$ or more. Maximum vegetative cover and leaf turgidity as well as straw yield were maintained with increased irrigation level. Hochman (1982), and Pal et al. (1996) confirmed these findings.

Flat sowing was superior to ridge sowing owing to the profuse tillering and vegetative growth induced by space and light availability as mentioned previously. Mahdi et al. (1998) reported similar findings such that flat sowing was richer in terms of LAI and plants/m$^2$. 

Interaction effect between tillage and water amount (Table 4.7) revealed that the high LAI values were almost associated with plough-till x richer irrigation levels. Chisel and disc ploughs x (80% - or 100% ETc) represents the best combination. The former plough maintains deep rooting, while the latter enables profuse shallow rooting density, which highlights the complementary role of both systems with respect to moisture and nutrient extraction. No-till was the poorest component on this regard as elaborated previously. Maurya (1989), and Meek et al. (1992) were in line with these conclusions.

5.5.4 Effect on number of effective tillers

Referring to Tables (4.5a, 4.5c and 4.5e) and Figs. (4.6a, 4.6b and 4.6c), it is evident that, throughout the prescribed seasons of study, plough-till treatments were significantly superior, and were almost identical in producing higher number of effective (productive) tillers on per plant or per unit area basis, when compared to no-till. Nevertheless, values pertaining to this parameter on per plant basis in this study, were generally within the two ranges of 1.0 to 1.5, and 1.5 to 2.0 as described by Moustafa et al. (1996), and Rawson (1986), respectively, as being
normal under Sudan conditions. Moreover, although tillering was potentially a genotypic characteristic, but it would considerably be affected by stand population, competition on inputs particularly nutrients and light, as well as on prevailing growing conditions. Unlike no-till systems, plough-till farming on such type of soil, which was fine-textured, compacted and with impeded macropore system resulting from intensive farming and lack of appropriate tillage measures, might be a necessity to provide seedbeds that would support soil-root-moisture inter-relations. Hence, tillering would be activated when signs of lack of nutrition and moisture disappear or last.

Similar findings were confirmed by Maurya (1989), Wilkins et al. (1989), Hammel (1995), Moustafa et al. (1996) and Tareq (1996).

Number of effective tillers was found to be significantly affected by irrigation regimes (Tables 4.5b, 4.5d and 4.5f) such that, maximum values were recorded when full irrigation amount in terms of crop evapotranspiration (100% ETc) was applied, compared to the remaining levels, in all seasons. Similar results were reported by Hussein et al. (1978), and Moustafa et al. (1996) who recorded maximum number of effective tillers with
increased levels of irrigation towards full water requirements.

Flat sowing was superior to ridge sowing in producing higher number of tillers in all seasons. This was in line with the results obtained by Roy et al. (1992), Mahdi et al. (1998), and Singh et al. (1998) most probably due to ample space, nutrients, light, and root density and mass.

Interaction effect between tillage and water amount (Tables 4.8a and 4.8b) generally revealed the superiority of plough-till x 100% ETc combination. This result was justifiable since profuse tillering would be induced by profuse shallow or deep rooting to alleviate the risks of moisture deficiency, the conditions that will be expected to prevail with plough-till. Such statements were reported by Hussein et al. (1978), Bukhari et al. (1992), Moustafa et al. (1996), Tareq (1996), and Hajabbasi (2001).

5.5.5 Effect on leaf turgidity (LT, %)

Leaf turgidity (LT) was found to be significantly (P < 0.05) affected by water amount in the two seasons considered (Table 4.5b and 4.5d). Higher LT values were associated with higher levels of irrigation (100% - or 80% ETc) which were statistically similar. This result was in
agreement with Farah’s (1995) who reported maximum LT of over 40% when he maintained his irrigation regimes at full rate of consumptive water use (CWU, m³/ha).

The superiority of flat sowing might be attributed to reduced competition in space, light, nutrients and water, as well as profuse rooting, which in turn improved the vegetative cover characteristics as reported by many workers previously cited.

5.6 Effect of tillage methods, watering regimes, method of sowing, and their interactions on yield and its components
5.6.1 Effect on number of fertile spikelets, and number of seeds per spike

Although significant variations in number of both fertile spikelets and seeds per spike were recorded as due to tillage and watering regimes, but however, the numerical observations of each parameter were very close (Tables 4.9a - 4.9f).

Both parameters were significantly lower in no-till treatments when compared to plough-till, mostly due to the previous justifications pertaining to improvements in rooting system that enabled better moisture, nutrition, aeration, and relevant input status in plough-till. These
conditions allowed plants to show their maximum potentialities and performance, in comparison to no-till environment. However, it is very difficult to consistently relate a given ploughing system to a definite level of either parameter, most likely due to the difficulty in isolating the effect of tillage, particularly in the short run. The superiority of plough-till in inducing a positive performance of similar yield components of wheat was stated by Abdul Razzaq et al. (1993), and Singh et al. (1998).

Investigations about the effect of water amount on the prescribed parameters showed that much irrigation water (100% - or 80% ETc) was needed to produce significantly higher number of both fertile spikelets and seeds per spike (Table 4.9b, 4.9d and 4.9f). This was expected since both parameters were very sensitive to water deficiency owing to its significant effect on final yield. Both Moursi et al. (1979) and Guerra (1995) reported significant reductions in these parameters when moisture was deficient, particularly at heading and through booting. Ishag (1995) also confirmed this result when he recorded induced spikelets abortion when moisture stress coincided with heading until early grain filling.
Interaction effect of tillage x water amount also revealed the superiority of deep ploughing x richer irrigation regimes, which justified the results obtained.

5.6.2 Effect on weight of spike (g)

No-till system gave the least weight of spike (g) in two seasons, compared to plough-till systems as shown in Tables (4.9a and 4.9c) and Figs. (4.7a, 4.7b and 4.7c). Similar findings were confirmed by Roy et al. (1992) who attributed his results to the drawbacks of no-till system, which were previously out-lined, particularly in the short run. On the other hand, weight of spike recorded by disc plough treatment (2.47 g) in the first season might be somewhat exaggerated and does not relate to statistical homogeneity. However, other plough-till treatments were statistically similar. In the second season, offset disc harrow and ridger were statistically superior, followed closely by chisel system which again confirmed the complementary effects of plough-till systems in modifying and supporting the rooting characteristics according to mode and depth of ploughing. Similar conclusions might be drawn from Reeder (1989), Singh et al. (1998), and Hajabbasi (2001).
In all seasons, maximum weights of spike (g) were recorded from higher irrigation levels (100% - and 80% ET<sub>c</sub>), in comparison to the lesser amount (60% ET<sub>c</sub>), as shown in Tables (4.9b, 4.9d and 4.9f). This might be attributed to the non-stressed conditions of moisture at time of spikelet development and grain filling. Such remarks might be understood from Farah (1995) and Ibrahim (1995) who reported that higher yields could be obtained when moisture stress at reproductive stages (booting and anthesis) was avoided. Moreover, Farah et al. (1993) confirmed that even yield gaps between cultivars could be minimized with moisture availability. Heavier ear weights from richer irrigation levels were also recorded by Hussein et al. (1979), Hochman (1982), and Guerra (1995).

Flat sowing was superior to ridge sowing in two seasons. This might be due to heavier grains, of greater number being produced in seedbeds of superior quality in terms of soil – moisture – plant relations as discussed earlier, and further confirmed by Roy et al. (1992), and Singh et al. (1998).

5.6.3 Effect on number, and weight (g) of seeds/plant
As shown in Tables (4.9a, 4.9c and 4.9e) and Figs. (4.8a, 4.8b and 4.8c), both parameters were significantly affected by tillage methods such that plough-till was superior to no-till. Such generalization was reported by Roy et al. (1992), and Singh et al. (1998). On the other hand, deep ploughing systems in general and ridger ploughing in particular were the best options in producing seeds that were heavier and dense in almost all seasons of study.

Richer irrigation regimes (100% - and 80% ETc) were very effective in terms of the prescribed parameters when compared to the stressed regime (60% ETc) as displayed in Tables (4.9b, 4.9d and 4.9f). In fact, richer watering regimes were found to be superior in producing higher number of effective tillers, maximum LAI, heavier grains and ears, as well as greater number of grains per ear in this study. All these parameters were major components of grains’ characteristics on per plant basis. These results were further confirmed by Moursi et al. (1979) who generalized that more than 75% in terms of consumptive use of water (CU, m³/ha) is enough to attain maximum performance of these parameters.

5.6.4 Effect on 1000-grains weight (g)
In two seasons, plough-till systems were significantly superior to no-till regime in terms of 1000-grains weight (Tables 4.9a, 4.9c and 4.9e). Similar generalization was reported by Roy et al. (1992), and Singh et al. (1998) when working in a fine-textured soil, under tropical conditions. They added that, extra benefit in wheat yield and its components could be gained from plough-till than from no-till. They attributed low yields from no-till plots to shrunked seeds as an outcome of lack of moisture and nutrition. Values obtained in this study that pertain to 1000-grains weight (g) were generally within the acceptable range recorded by Babiker et al. (1991) in Sudan Gezira, as well as Ghorashi (1990) and Abdel Gadir (1994) in New Halfa.

The least irrigation regime (60% ETc) produced grains that were significantly smaller and lighter than those obtained from the richer irrigations which were statistically similar in the three seasons of study (Tables 4.9b, 4.9d and 4.9f). These results are in conformity with Ahmeds’ (1992) who reported significant reductions in grain size of wheat under water stress conditions that coincided with early grain filling. In fact, water stress might imply extended irrigation intervals based on conventional (100% ETc)
amounts, skipping irrigation, phasic irrigation, or application of deficit amounts at conventional intervals.

5.6.5 Effect on total grain yield (t/ha)

As shown in Figs. (4.9a, 4.9b and 4.9c), tillage methods have significantly affected grain yield throughout the three seasons of study. Plough-till treatments were significantly superior to no-till system in terms of attainable grain yield (t/ha). Many workers including Michael et al. (1983), Maurya (1989), Raines and Bicki (1993), Liebharo (1995), Tareq (1996), Roy et al. (1992) and Singh et al. (1998) reported similar findings. They attributed their findings to the impeded macropore system continuity associated with no-till regimes, which arises from crusting, compaction, higher penetration resistance of soil under poor, non-sustainable mulch cover conditions as elaborated earlier. The effect of higher bulk density and compaction would be offset with time when biological activities underneath are efficient to create and sustain macropores. Aeration, moisture extraction, root proliferation, and nutrients’ uptake will then be secured for healthy and active crop growth, which will otherwise be stunted and terminated.
Many workers did not report any significant differences in wheat yields between plough-till and no-till regimes under conditions when a well-managed and sustainable mulch cover on no-till plots was secured (Aslam et al. 1989; Lonita et al. 1999; Mahey et al. 2002; and Zentner et al. 2002).

When individual plough-till systems were evaluated, it is evident that ridger system was the best in terms of grain yield, followed by offset disc harrow regime, throughout the three seasons of study. Disc plough was the poorest. Based on the mode of action, ridger was a deep ploughing implement, which could effectively break underlying pans and hence induces deep rooting. Offset disc harrow maintains a shallow, well-disturbed and crumbled seedbed and in turn induces shallow rooting. Both rooting characteristics could enable appreciable use of input resources in the soil, as confirmed by Reeder (1989), and Bukhari et al. (1992). On the other hand, the obtainable benefits from disc ploughing might be offset by the subsequent compaction resulting from the prementioned static and dynamic weights. Moreover, the pulverization action resulting from the huge mechanical impact of the plough tends to produce greater amounts of finer soil
particles which makes the chance for macropore blockage by these particles more probable, when compared to offset disc harrow system. Nevertheless, disc plough system was superior to no-till in terms of grain yield of wheat. Similar conclusions were drawn by Hammel (1995). Also Musik et al. (1994) agreed with all these findings and further commented that, water deficit risks might be alleviated by improving rooting environment by plough-till.

Throughout the three seasons of study, both 100\% ET\textsubscript{c} and 80\% ET\textsubscript{c} irrigation regimes were statistically similar and superior to the 60\% ET\textsubscript{c} regime in terms of grain yield (t/ha) as evident in Tables (4.9b, 4.9d and 4.9f). The positive and linear relationship between grain yield of wheat and crop evapotranspiration (ET\textsubscript{c}) was highlighted by Musik et al. (1994) particularly under dryland irrigated conditions. Moursi et al. (1979) recorded up to 43\% increases in grain yield assessed from yield components when moisture stress was kept at 25\% ET\textsubscript{c}, particularly after booting. Hochman (1982) also stated similar observations when he recorded maximum grain yields losses of up to 36\% and 28\% when 70\% ET\textsubscript{c} irrigation regime was restored from anthesis to grain filling, and from tillering to anthesis, respectively. These results were
confirmed by Hussein et al. (1978) who recorded maximum grain yields from his 100% ETc irrigation regime, due mainly to abundant tillering, and heavier spikes and grains assessed on 1000-weight basis. Similarly, Thakur (1987), Farah et al. (1992), and Guerra (1995) were in line with the conclusions that reductions in grain yield of wheat were inevitable outcome of the negative effect of water deficit on major yield components such as number of spikes/m², number of spikelets/spike and number of grains/spike, which was proved in previous sections of this text.

Flat sowing was significantly superior to ridge planting in terms of grain yield of wheat in two seasons. Results pertaining to growth and yield attributes in this study revealed that number of productive tillers, LAI, and weight of spike (g) recorded superior results on flat beds, which might cumulatively outweigh other components in favour of flat sowing on grain yield basis. These results were fairly in line with Mahdi et al. (1998) who recorded poor performance remarks for ridge sowing in comparison to flats. Flat sowing was also proved to be superior to ridge sowing by Roy et al. (1992), and Singh et al. (1998) particularly under plough-till farming. They even recommended ridge planting for no-till systems, mostly for
better water management and control. Further confirmations were stated by Babiker and El Hassan (1990) but with slight preference to flat sowing since ridges provided better weed control and stand establishment. Salih and Musa (1989), Salih et al. (1990), and Babiker and Mohamed (1992) were in line with the last worker. In contrast Omer (1990), and Dawelbeit and Babiker (1997) recorded that flat sowing was significantly inferior to ridge sowing in terms of final grain yield since the latter method maintained better stand establishment, and greater number of heavier heads/m². Many other researchers were in line with these results (Satti 1990; Taha 1990; and Dawelbeit et al. 1992). They attributed their conclusions to the observations that, in ridge sowing, seeds and water might not have the chance to escape through cracks, particularly during the first irrigation, as the case with flat sowing.

Interaction effect between tillage and method of sowing was reported in two seasons. No-till was inferior irrespective to sowing method in both seasons, but ridge sowing was numerically superior as previously confirmed by Singh et al. (1998) in controlling crusting, weeds, and flooding hazards. However, maximum grain yields were obtained from ridger, or offset disc harrow, x flat sowing in
two seasons, as well as ridger system x ridges, and chisel system x flat sowing, in one season. These findings were previously elaborated in this text. The superiority of offset disc harrow system x ridge sowing was confirmed by Salih and Musa (1989) and Salih et al. (1990). Dawelbeit and Babiker (1997) even found that offset disc harrow system x flat sowing was better than disc plough system x flat, which further confirmed the results obtained in this study. In fact, it is statistically similar to adopt either method of sowing with disc plough system since the plough would induce profuse rooting density at shallow depths rather than deep rooting, which implies that only the water at that shallow depth will be of concern, particularly under conditions of scanty water streams. Generally, this system was the poorest among plough-till systems in this study. This result was confirmed by Guy and Cox (2002) when they recorded its inferior results in obtaining final grain yields of wheat compared to chisel system.

5.6.6 Effect on harvest index (HI, %)
Throughout the three seasons of study, plough-till was found superior to no-till in terms of this parameter (Tables 4.9a, 4.9c and 4.9e). However, variations between plough-till systems within each season were very slight, although significant, to make them almost comparable. But however, offset disc harrow system was the best among plough-till regimes. Moreover, unlike plough-till, HI values obtained from no-till plots were even below the optimum range of 35 to 45% stated by Doorenbos and Kassam (1986), and Mohamed (1995) under irrigated conditions. This might be attributed to the deteriorated performance of HI components such as lesser number of grains, shrunked or lighter ears and grains as well as less ears/m² as discussed in previous sections in this chapter.

Effect of irrigation regime on HI was recorded in all seasons of study (Tables 4.9b, 4.9d and 4.9f). The highest HI values were associated with 100% - and 80% ETc regimes as statistically comparable options, in comparison to no-till. This result was expected owing to the fact that all yield components, and total yield were statistically maximized at almost either of the prescribed irrigation regimes as elaborated earlier in this chapter. These results were confirmed by Hussein et al. (1978), and Pal et al.
(1996) who further generalized that even straw and overall dry matter yields can be maximized at higher irrigation levels.

Flat sowing was proved superior to ridge sowing since major HI components, namely number, and weight of grains and ears, as well as net grain yield were also maximum with flat sowing.

5.7 Effect of watering regimes on water use efficiency (WUE, kg/m³)

As shown in Fig. 4.11, in all seasons, WUE was maximized at the intermediate irrigation regime (80% ET₀), followed by the least regime (60% ET₀). This result might be justified on the basis of phasic development stages of wheat, such that WUE could be maximized when full crop water requirements (100% CWR) are satisfied only at the reproductive stages for higher economic yield to be attained. In other words, one or more irrigations might be omitted, or long irrigation intervals of up to 28 days could be maintained during the early (vegetative), or late (ripening) stages without significant reduction in grain yield. Hence, the 100% ET₀ irrigation regime throughout the growth cycle of the crop might indicate an over-irrigation regime that would not support the item of cost-
effectiveness as a major component in economic irrigation. On the other hand, leaf turgidity (LT, %) was statistically maximized at 100% - and 80% ETc irrigation regime in this study. This result was in line with the prementioned finding since higher WUE values were associated with higher LT (%) and grain yield. This conclusion was in agreement with Hochman (1982), Ahmed (1992), Farah et al. (1993), Farah et al. (1994), Farah (1995), and Ibrahim (1995) who generally maximized their grain yields of wheat, based on WUE maximization when water stress was avoided only at the reproductive stages (between booting and grain filling).

On the other hand, when full irrigation levels (100% CWR) were maintained throughout the crop development cycle, WUE would most probably be maximized due to enough moisture being available at the reproductive stages in particular.

Based on Table 4.11, it is evident that the full irrigation regime that is conventionally used at the Sudan Gezira was 25% less than the mean actual water requirements stated by Farah (1995) for obtaining the highest yield. This amount was expected to decrease northward if the crop is to restore the same life span and number of irrigations as the case in this study. Moreover, since WUE maximization is based on 80% ETc irrigation
regime, up to 17% and 56% water savings over conventional and actual amounts will be guaranteed, respectively. Such variations in irrigation practices are major reasons behind yield discrepancies of wheat as agreed upon by Faki (1995).
CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

Based on the results of this study, the following conclusions may be drawn:

- Plough-till was generally superior to no-till for wheat production under Shambat conditions.

- Effect of tillage method and depth on bulk density and porosity would hardly be related to a specific trend.

- Both ridger and offset disc harrow systems were equally superior to disc and chisel plough and no-till, and reflect the complementary effects of both deep-ploughed -(deep rooting), and shallow-pulverized -(profuse rooting) seedbeds to accommodate for seedling emergence and development, respectively.

- Disc plough has the least operating capacity, but the greatest draft and power requirements, as well as the least slippage (equally with chisel plough), which lend more fuel to be consumed at work. Offset disc harrow, on the other hand has the least slippage and fuel consumption rate.

- Flat sowing was either similar to or better than ridge sowing and produced higher levels of yield (grain + straw). It was even better when scanty irrigation streams were applied to non-cracky profiles.

- Irrigation levels of (100% and 80% ETc) were statistically similar and superior to 60% ETc in producing maximum grain yield of wheat.
- Maximum water use efficiency was obtained at 80% ET$_c$ watering regime, while the lowest value was recorded by the 100% ET$_c$ regime.

- Ridger (or offset disc harrow) systems by 80% ET$_c$ and flat sowing was the best combination of soil and water management option for wheat production under Shambat conditions.

2- Recommendations

On the basis of the results and conclusions obtained from this study, the following recommendations can be made:

- Plough-till is the most suitable choice for wheat production, and that offset disc harrow, and ridger systems are the best option.

- Soil compaction and weeds (or weeding costs) are the major inherent problems of no-till system under almost all farming conditions, which necessitate more intensive investigation if such a system is to be economically implemented.

- If a shallow, well-pulverized seedbed is needed, disc plough should be substituted by disc harrows for optimizing time, fuel, and power efficiencies. Similarly, the ridger might be a prefect substitute to chisel plough when deep ploughing is required.

- Future research scopes on wheat mechanization should focus on alleviating the secondary compaction resulting from mechanical land preparation measurements as it alter the positive outcomings of the operation and hinder irrigation water infiltration with time.

- Inline with the concept of sustainable and economic resource management, the 80% ET$_c$ watering regime is most suitable for producing wheat as far as water use efficiency is concerned.
- Work on varietal response to phasic irrigation, and skipping irrigation is needed to adjust the optimum combinations based on variety and its developmental stage.

- Research is needed to identify the least CWR of the crop based on its most critical stages at farm level.

- Between 80 - 60% ETc, a potential research task and knowledge pertaining to wheat irrigation need to be highlighted.

REFERENCES


National Coordination Meeting, 29 Aug. – 2 Sept. 1993, ARC, Wad Medani, Sudan.


Mahey, R.K.; Singh, O.; Singh, A.; Brar, S.S.; Virk, A.S. and Singh, J. (2002). Effect of First, Subsequent Irrigation (s) and Tillage on Grain Yield, Nutrients Uptake, Rooting Density of Wheat,


Mohamed, M.A. (2000). Effect of Duration of Water Ponding on Soil Water, Plant Growth and Yield and Yield Components of Wheat at Different Growth Stages. ARC, Ministry of


APPENDICES

Appendix A.1. Sample calculation of the crop water requirements \((ET_c \%)\) on the basis of the modified Penman (1977) method for estimating \(ET_a\) (mm/day).

Site: Shambat, Faculty of Agric., University of Khartoum

Month: January 2001

**Shambat Meteorological Station**

<table>
<thead>
<tr>
<th>Ref. Date</th>
<th>Temperature (°C)</th>
<th>Relative humidity (RH%)</th>
<th>Wind speed (U)</th>
<th>Sunshine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max.</td>
<td>Min.</td>
<td>Mean</td>
<td>Max.</td>
</tr>
<tr>
<td>Jan. 1</td>
<td>33.0</td>
<td>22.5</td>
<td>27.8</td>
<td>46.0</td>
</tr>
</tbody>
</table>
\[
ET_o = C \left( W \cdot R_n + (1 - W) \cdot f(u) \cdot f(e_a - e_d) \right) \text{ mm/day}
\]

\[
ET_c = ET_o \cdot K_c \text{ mm/day}
\]

- Calculating the difference in vapour pressure \((e_a - e_d)\) mbar
  - \(e_a\) at \(T_{\text{mean}}\) (Table 1) = 37.40 mbar
  - \(e_d = e_a \times \text{RH}_{\text{mean}}\) (decimal) = 13.65 mbar
  - \(e_a - e_d\) = 23.75 mbar

- Calculating the wind function \([f(u)]\)
  \[
f(u) = 0.27 \left(1 + \frac{u}{100}\right) \text{ (or directly from Table 2)},
  \]
  Where: \(U\), wind speed km/full day (24 hr) at 2 m height,
  \(f(u)\), = 0.62

- Calculating weighting factors, \((1 - W)\) and \(W\), altitude (380 m),
  and \(T_{\text{mean}} = 27.8^{\circ}\text{C}\)
  With aid of Table 3 and 4,
  \(1 - W\) = 0.22
  \(W\) = 0.78

- Calculating net Radiation \((R_n)\)
  \[
  R_n = R_{ns} - R_{nf} \text{ depending on altitude and month}
  \]
  \[
  R_{ns} = (1 - \alpha)R_s
  \]
  \[
  R_s = (0.25 + 0.5 \frac{n}{N}) R_a \text{ mm/day}
  \]
  With aid of Table 5 for obtaining \(R_a\), Table 6 for obtaining \(N\), or directly from Table 7 to obtain the ratio \(R_d/R_{ns}\) at \(\alpha = 0.05\) (correction factor).
\[ R_{ns} = 6.86 \text{ mm/day} \]
\[ R_{nf} = f(t) \cdot f(e_d) \cdot f(n/N) \]

With aid of Table 8, 9 and 10
\[ R_{nf} = 2.93 \text{ mm/day} \]
\[ \therefore R_n = 3.93 \text{ mm/day} \]

- Calculating the adjustment factor (C) on the basis of \( R_s, RH_{U_{day}} \) (m/sec), and \( U_{day} \), and with aid of table (11):

\[ 0.98 = C \]

by substituting all variables in the equation
\[ ET_o = 6.18 \text{ mm/day} \]
\[ K_c = 1.15 \]
\[ ET_c = 7.11 \text{ mm/day} \]
Appendix B.

Table 1. Effect of tillage methods (T), water regimes (W, %ETc), method of sowing (S), and their interactions on growth components of wheat; 1st season (2000/01).

<table>
<thead>
<tr>
<th>Experimental factors</th>
<th>Corresponding F_{0.05} (tab.)</th>
<th>Tillage M. (T)</th>
<th>Water R. (W)</th>
<th>Method of sowing (S)</th>
<th>T X</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3.84</td>
<td>6.94</td>
<td>2.59</td>
<td>2.6</td>
</tr>
</tbody>
</table>

1. Plant population at emergence (plants/m²)  
2. Plant height (cm), 3WAS  
3. Plant height (cm), 6WAS  
4. Plant height (cm), 9WAS  
5. Plant height (cm), 12WAS  
6. Plant height (cm), at harvest  
7. Leaf area index (LAI)  
8. Leaf turgidity (LT, %)  
9. Number of effective tillers (heads)/plant  
10. Number of effective tillers (heads)/m²  
11. Plant population at harvest (plants/m²)

WAS = Weeks after sowing. * Denotes significance at 5% level.

Table 2. Effect of tillage methods (T), water regimes (W, %ETc), method of sowing (S), and their interactions on growth components of wheat; 2nd season (2001/02).

<table>
<thead>
<tr>
<th>Experimental factors</th>
<th>Corresponding F_{cal.} V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tillage M. (T)</td>
</tr>
<tr>
<td></td>
<td>3.84</td>
</tr>
</tbody>
</table>

1. Plant population at emergence (plants/m²)  
2. Plant height (cm), 3WAS  
3. Plant height (cm), 6WAS  
4. Plant height (cm), 9WAS  
5. Plant height (cm), 12WAS  
6. Plant height (cm), at harvest  
7. Leaf area index (LAI)  
8. Leaf turgidity (LT, %)  
9. Number of effective tillers (heads)/plant  
10. Number of effective tillers (heads)/m²  
11. Plant population at harvest (plants/m²)
Table 3. Effect of tillage methods (T), water regimes (W, %ETc), method of sowing (S), and their interactions on growth components of wheat; 3rd season (2002/03).

<table>
<thead>
<tr>
<th>Experimental factors</th>
<th>Corresponding F_{cal. V}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tillage M. (T)</td>
</tr>
<tr>
<td>Corresponding F_{0.05 (tab.)}</td>
<td>4.76</td>
</tr>
</tbody>
</table>

1. Plant population at emergence (plants/m²)  
2. Plant height (cm), 3WAS  
3. Plant height (cm), 6WAS  
4. Plant height (cm), 9WAS  
5. Plant height (cm), 12WAS  
6. Plant height (cm), at harvest  
7. Leaf area index (LAI)  
8. Leaf turgidity (LT, %)  
9. Number of effective tillers (heads)/plant  
10. Number of effective tillers (heads)/m²  
11. Plant population at harvest (plants/m²)

WAS = Weeks after sowing. * Denotes significance at 5% level.
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Number of effective tillers (heads)/plant</td>
<td>15.51*</td>
<td>90.6*</td>
</tr>
<tr>
<td>9. Number of effective tillers (heads)/m²</td>
<td>19.98*</td>
<td>139.59*</td>
</tr>
<tr>
<td>10. Plant population at harvest (plants/m²)</td>
<td>37.44*</td>
<td>16.79*</td>
</tr>
</tbody>
</table>

WAS = Weeks after sowing. * Denotes significance at 5% level.
Table 4. Effect of tillage methods (T), water regimes (W, %ETc), method of sowing (S), and their interactions on yield and yield components of wheat; 1st season (2000/01).

<table>
<thead>
<tr>
<th>Experimental factors</th>
<th>Corresponding F&lt;sub&gt;cal. V&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tillage M. (T)</td>
</tr>
<tr>
<td>Values of F&lt;sub&gt;0.05 (tab.)&lt;/sub&gt;</td>
<td>3.84</td>
</tr>
<tr>
<td>1. Number of fertile spikelets/spike</td>
<td></td>
</tr>
<tr>
<td>2. Number of seeds/spike</td>
<td>3.98*</td>
</tr>
<tr>
<td>3. Weight of spike (g)</td>
<td>34.00*</td>
</tr>
<tr>
<td>4. Number of seeds/plant</td>
<td>47.31*</td>
</tr>
<tr>
<td>5. Weight of seeds/plant (g)</td>
<td>11.46*</td>
</tr>
<tr>
<td>6. Thousand-grain weight (g)</td>
<td>115.68*</td>
</tr>
<tr>
<td>7. Total grain yield (t/ha)</td>
<td>68.92*</td>
</tr>
<tr>
<td>8. Harvest index (H.I, %)</td>
<td>27.04*</td>
</tr>
</tbody>
</table>

* Denotes significance at 5% level.
Table 5. Effect of tillage methods (T), water regimes (W, %ETc), method of sowing (S), and their interactions on yield and yield components of wheat; 2nd season (2001/02).

<table>
<thead>
<tr>
<th>Experimental factors</th>
<th>Corresponding $F_{\text{cal.}}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values of $F_{0.05}$ (tab.)</td>
<td>$3.84$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Tillage M. (T)</th>
<th>Water R. (W)</th>
<th>Method of sowing (S)</th>
<th>T X</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number of fertile spikelets/spike</td>
<td>$32.78^*$</td>
<td>$179.60^*$</td>
<td></td>
<td>$7.01$</td>
</tr>
<tr>
<td>2. Number of seeds/spike</td>
<td>$8.84^*$</td>
<td>$29.45^*$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Weight of spike (g)</td>
<td>$15.30^*$</td>
<td>$16.47^*$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Number of seeds/plant</td>
<td>$59.48^*$</td>
<td>$28.54^*$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Weight of seeds/plant (g)</td>
<td>$9.48^*$</td>
<td>$23.59^*$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Thousand-grain weight (g)</td>
<td>$56.58^*$</td>
<td>$64.12^*$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Total grain yield (t/ha)</td>
<td>$70.75^*$</td>
<td>$14.70^*$</td>
<td>$6.19^*$</td>
<td></td>
</tr>
<tr>
<td>8. Harvest index (H.I, %)</td>
<td>$35.68^*$</td>
<td>$37.75^*$</td>
<td>$8.65^*$</td>
<td></td>
</tr>
</tbody>
</table>

* Denotes significance at 5% level.
Table 6. Effect of tillage methods (T), water regimes (W, %ETc), method of sowing (S), and their interactions on yield and yield components of wheat; 3\textsuperscript{rd} season (2002/03).

<table>
<thead>
<tr>
<th>Experimental tractors</th>
<th>Corresponding F\textsubscript{cal}. V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tillage M. (T)</td>
</tr>
<tr>
<td>Values of F\textsubscript{0.05} (tab.)</td>
<td>4.76</td>
</tr>
</tbody>
</table>

1. Number of fertile spikelets/spike 17.42* 32.35* 5.4€
2. Number of seeds/spike 101.95* 9.75*
3. Weight of spike (gm) 12.89*
4. Number of seeds/plant 10.43*
5. Weight of seeds/plant (gm) 9.42* 15.06*
6. Thousand-grain weight (gm) 4.88* 27.60*
7. Total grain yield (t/ha) 15.95* 57.70*
8. Harvest index (H.I, %) 26.44* 9.81*

* Denotes significance at 5% level.
Appendix 4

Wheat origin and recognition

Raemaebers (2001), Onwume and Sinha (1991) reported that wheat, which belong to the genus *Triticum* of the family poaceae (graminae) was originated in the Fertile Crescent in the Near and Middle East. It was introduced into Africa through Kenya, Congo-Kinshasa and Ethiopia. Among all its species, only bread and durum wheats are of commercial interest in tropical Africa.

Ecology and Adaptation

Doorenbos and Kassam (1986); Onwueme and Sinha (1991); Raemaebers (2001) and Curtis *et al.* (2002) mentioned that, wheat is the most widely grown, widely adapted food crop in the world, stretching between latitudes of 30° 60°N and 27° and 40°S, from sea level (sL) to > 3000 m asL when reported at Tibet (4750 m asL). Minimum and maximum temperatures for growth are 3° to 4°C and 30° to 32°C, respectively. optimum temperature is 25°C. Better adopted to medium-textured soils of pH 6-8. Total growing period of spring wheat is 100-130 days.

Onwueme and Sinha (1991); Raemaekers (2001) and Sayre (2002) stated that the temperature irrigated areas of Asia are the most important agroecological habitat where 90% of its irrigated wheat is produced in India, Pakistan, Iran etc… Its basically an intensively managed (rainfed) in developing and developed countries, where 42% and 5% of total production is by irrigation, respectively. Sudan is part of the high temperature areas of the developing areas where 6% of spring wheat is produced. In Africa, Sudan is part of the tropical Africa
Regional Group which constitutes > 40 countries lying between the tropics of Cancer (23°N) and Copricorn (23°S).

**World production**

Curtis *et al.* (2002) reported that current world wheat production is about 600 metric tonne from 240 m ha, with major production intensity in temperate zones. However, by 2030, additional 250 mt is needed to cope with the increased demand as world population is expected to approach 6 billions at 2020 (Sadik, 1994), and 10 billions by 2050 (FAO, 1995). On the other hand, major food crises were expected in the subsaharan Africa and tropical Asia, where increases in production should focus on increasing yield/unit area, as expansion in area is facing many limitations (Evans, 1998).

Africa as a content produces only 2.46% of total world production grown only during winter, mostly by irrigation. Tropical Africa is the least sharer and only four countries, viz. Zembabwe, Sudan, Ethiopia and Kenya are major producers amounting to only 0.1 mt. (Onwueme and Sinha, 1991 and Raemakers, 2001). In the Sudan, wheat is the second most important cereal after sorghum in the diet (Farah, 1995). The area devoted annually to wheat is about 300,000 ha grown entirely under irrigation with river flows or ground water.