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**EFFECTS OF STUBBLE MANAGEMENT, TILLAGE AND CROPPING  
SEQUENCE ON SUSTAINABLE WHEAT PRODUCTION IN THE  
SOUTH-EASTERN HIGHLANDS OF ETHIOPIA**

by

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**DECLARATION**

I declare that the dissertation hereby submitted by me for the Philosophia Doctor degree at the University of the Free State is my own independent work and has not previously been submitted by me at another university/faculty. I furthermore, cede copyright for the dissertation in favour of the University of the Free State.

Signed

A handwritten signature in black ink, consisting of a series of loops and strokes, positioned above a horizontal line.

Asefa Taa Woyessa

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## ABSTRACT

Bread wheat (*Triticum aestivum*) is one of the major cereals produced in south-eastern Ethiopia. Yields are often low on peasant farmers' fields due to sub-optimal crop management practices. Four multi-factor crop management trials were conducted which ran from 1992 till 2000 at Kulumsa and Asasa in the south-eastern highlands of Ethiopia. Two trials were conducted at each location, one where an ox-plow was used to simulate the peasant farmers methods and on the other trial mechanized farming methods were used. Different crop residue management options, tillage practices and cropping sequences were included as treatments. The crop residue management treatments were burning, partial removal (to simulate grazing by animals) and complete crop residue retention. The tillage practices for the mechanized trial were conventional mouldboard plowing, conservation tillage which was zero tillage at Kulumsa and minimum tillage at Asasa and for the ox-plow trials it were conventional ox-plowing and minimum tillage. The cropping sequences were continuous wheat and a rotational system of faba beans (*Vicia faba*) followed by two seasons of wheat. The soil types were a clay intergrade between an eutric Nitisol and a luvisol Phaeozem with 50% clay in the topsoil at Kulumsa, and a clay loam calcic Chernozem with 36% clay in the topsoil at Asasa. The objective of the study was therefore to determine the integrated effects of cropping sequence, straw management and tillage practices on the productivity and sustainability of wheat-based farming systems in Ethiopia.

Among the crop residue management treatments, burning of stubble tended to increase the grain and biomass yield, as well as the yield components of wheat in most of the years when compared to partial removal and complete retention of stubble. Tillage did not give consistent responses for most of the parameters in either of the trials, with the exception of thousand kernel weight which was consistently higher for zero or minimum tillage in most seasons. Conventional tillage tended to be the superior tillage practice in terms of most of the measured parameters. The faba bean cropping sequence markedly increased wheat yields and the yield components, especially in the first wheat crop following faba beans. This can be ascribed to a higher soil N status. Burning of stubble tended to also enhance wheat N uptake as compared to partial removal or complete retention of the straw.

Stubble management and cropping sequence had relatively minimal effects on soil strength expressed as penetrometer resistance. Conservation tillage led to a higher penetrometer resistance particularly in the surface layer of the soil (i.e., 0-15 cm depth), in both the mechanised and ox-plow systems, compared to conventional tillage. The penetrometer resistance of the 0-5 cm depth was negatively related to grain yield, while the penetrometer resistance of at the 20-25 cm depth was positively related to grain yield.

Retention of straw on the soil surface increased the concentration of most of the important plant nutrients in the upper layer (i.e., 0-15 cm) of the soil as compared to burning and partial removal of the straw. Zero or minimum tillage practices also increased the concentration of some important plant nutrients like phosphorus and potassium in the upper layer of the soil in both system trials. Cropping sequence had little effect on the soil chemical properties.

Partial removal or retention of the stubble tended to increase the population density of some broadleaf weed species, while burning had the opposite effect. Burning of crop stubble also markedly reduced the total grass weed population as compared to the other straw management treatments. Broadleaf weed populations were not affected by tillage practices in either the ox-plow or mechanised trials. Grass weeds, however, increased significantly in density under minimum or zero tillage. Broadleaf weeds did not vary markedly in response to cropping sequence, but most of the grass weed populations decreased in the faba bean rotation.

A three years rotation, consisting of two consecutive wheat crops followed by one faba bean crop reduced the incidence of take-all, but had little effect on the eyespot incidence. Both zero or minimum tillage dramatically inhibited the take-all incidence relative to conventional tillage, but had little effect on eyespot incidences. Stubble burning had no consistent effect on the incidence of either of the diseases. The incidence of eyespot was higher in the full stubble retention practices compared to partial removal.

A partial budget analysis reflected that the practice consisting of faba beans in rotation with wheat, combined with stubble burning, was the lowest cost option for ox-plow production systems. The practice of a faba bean-wheat rotation plus full stubble retention was the lowest cost option for mechanised production systems. The economic optimum practice for both the mechanised and ox-plow systems at Kulumsa was combining stubble burning with conventional tillage and continuous wheat. However, for the Asasa mechanised trial the economic optimum practice was combining stubble burning with conventional tillage and a faba bean-wheat crop rotation, while for ox-plowing it was combining stubble burning with minimum tillage in a faba bean-wheat crop rotation. Moreover, the index of variability of the nett benefit of each trial did not vary markedly between the low-cost and the economic optimum treatments. This means that the stability of farm level income will not be affected significantly by adopting the economic optimum practices for each zone.

Pot experiments were conducted to determine the effect of the different straw management practices on wheat seedling development under controlled conditions. Straw retention had a negative effect upon most of the measured seedling growth parameters. The nil straw treatment (i.e., the control) grew better than the other application levels. Straw retention levels higher than 2.5 t ha<sup>-1</sup> impeded seedling development. Burning of the straw reduced the negative effect of straw application. The incorporation of the straw in to the soil resulted in the most pronounced inhibition of seedling development. The application of fresh straw was more harmful than naturally degraded straw.

*Key words* : Conservation tillage, Compaction, Crop residue, Crop Rotation, Faba bean, Grain yield, Nutrient uptake, Wheat.

## OPSOMMING

Broodkoring (*Triticum aestivum*) is een van die belangrikste grane wat in suidoos Ethiopië geproduseer word. Lae oesopbrengste word deur die bestaansboere behaal as gevolg van nie-optimale gewasbestuurspraktyke. Vier gewasbestuursproewe, wat elk vanaf 1992 tot 2000 geduur het, is te Kulumsa en Asasa in die suidoostelike hooglande van Ethiopië uitgevoer. Twee proewe is by elke lokaliteit uitgevoer, nl. een waar 'n osploeg en die tradisionele praktyke van die plaaslike boere toegepas is en die ander waar gemeganiseerde boerderymetodes gebruik is. Verskillende oesreste bestuursopsies, grondbewerkingspraktyke en gewasopeenvolgings is as behandelings ingesluit. Die oesreste bestuursbehandelings was brand, gedeeltelike verwydering (om beweiding van lande te verteenwoordig) en behoud van al die oesreste. Die grondbewerkingspraktyke vir die gemeganiseerde proewe was konvensionele skaarploegbewerking en bewaringsbewerking nl. deklaagbewerking by Asasa en geenbewerking by Kulumsa. Vir die tradisionele proewe was dit konvensionele osploegbewerking en minimumbewerking. Die gewasopeenvolgingsbehandelings was jaar-na-jaar deurlopend koring en 'n wisselboustelsel van boerbone (*Vicia faba*) gevolg deur twee seisoene koring. Die grondtipes was 'n klei tussengraad van 'n eutriese Nitisol en 'n luviese Phaezem met 50% klei in die bogrond by Kulumsa en 'n kleileem kalsiese Chernozem met 36% klei in die bogrond by Asasa. Die doel van die studie was om die geïntegreerde effek van oesrestebestuur, bewerkingspraktyke en gewasopeenvolging, op die volhoubaarheid van koringproduksie-boerderystelsels in Ethiopië te ondersoek.

Die verbranding van oesreste het in verskeie seisoene die hoogste graan en biomassa opbrengste gegee. Daar was geen konsekwente effek van grondbewerkingspraktyke op meeste van die oeskomponente nie, met die uitsondering van die duisendkorrelmassa wat altyd die hoogste op die geen- of minimumbewerking was. Konvensionele bewerkingspraktyke het geneig om die beste praktyk te wees in terme van al die gemete parameters. Die boerboon-koring wisselboustelsel het hoër koringopbrengste tot gevolg gehad, veral in die eerste seisoen koring wat op die boerbone gevolg het. Hierdie reaksie is veral aan 'n hoër grond- stikstofstatus toegeskryf. Die verbranding van oesreste het ook 'n verhoogde stikstofopname deur koring tot gevolg gehad.

Die oesrestebestuurs- en gewasopeenvolgingsbehandelings het min effekte op grondsterkte, uitgedruk as penetrometerweerstand, gehad. Die bewaringsbewerkingspraktyke het hoër penetrometerweerstande in die boonste 150 mm, as die konvensionele praktyke gehad. Die penetrometerweerstand vir die 0 tot 50 mm diepte het 'n negatiewe verwantskap met oesopbrengste gehad terwyl die waardes op 200 tot 250 mm diepte 'n positiewe verwantskap getoon het.

Behoud van alle oesreste op die oppervlak met bewaringsbewerking, het 'n verhoging van plantvoedingstofkonsentrasies in die boonste 150 mm tot gevolg gehad. Dit was veral die geval met fosfor en kalium.

Die brand van oesreste het die populasiedigtheid van verskeie breëblaar en gras onkruide vermeerder. Die populasie van breëblaaronkruide is nie deur bewerkingspraktyke ge-afekteer nie maar die populasiedigtheid van sommige grasspesies het veral betekenisvol toegeneem in die minimum- en geenbewerkingsbehandelings. Gewasopeenvolging het geen effek op die breëblaar onkruide gehad nie maar die graspopulasies het toegeneem by die boerboon-koring wisselboubehandelings.

Die boerboon gevolg deur die twee seisoene koring wisselboustelsel het die besmetting van vrotpootjie by koring bejerk maar geen effek op oogvlek gehad nie. Die voorkoms van vrotpootjie by koring was ook laer by die verskillende bewaringsbewerkingsbehandelings terwyl dit geen effek op oogvlek gehad het nie. Brand van oesreste het geen effek op die voorkoms van beide vrotpootjie of oogvlek gehad nie. Die voorkoms van oogvlek was hoër waar al die oesreste behou is, in vergelyking met gedeeltelike verwydering.

'n Gedeeltelike begrotingsontleding van die behandelings en behandelingskombinasies is gedoen. Dit het getoon dat 'n stelsel bestaande uit 'n boerboon-koring wisselboustelsel gekombineer met brand van oesreste die goedkoopste vir die tradisionele praktyk is. Vir die gemeganiseerde praktyke was wisselbou gekombineer met volle behoud van oesreste die goedkoopste stelsel. Die ekonomiese optimum stelsels vir beide die gemeganiseerde en tradisionele praktyke te Kulumsa, was 'n kombinasie van brand van oesreste met konvensionele bewerking en deurlopende

koringproduksie. Vir Asasa gemeganiseerd was dit 'n kombinasie van oesreste verbranding, konvensionele bewerking en boerboon-koring wisselbou. Vir die tradisionele praktyke te Asasa was dit brand in kombinasie met minimumbewerking en wisselbou. Vir al die proewe het die variasie-indeks van die netto voordeel tussen die goedkoopste en die ekonomiese optimum behandelingskombinasie nie noemenswaardig verskil nie. Dit beteken dat die stabiliteit van die plaasvlak inkomste nie veel deur die aanvaarding van die aanbevole stelsels ge-afekteer sal word nie.

Potproewe is uitgevoer om die effek van die verskillende oesreste bestuursopsies op die groei van koringsaailinge onder gekontroleerde toestande te ondersoek. Die behoud van koringstrooi het bykans al die groeiparameters van die koringplante benadeel, veral by vlakke hoër as  $2.5 \text{ t ha}^{-1}$ . Die verbranding van oesreste het die beste groei verseker terwyl die vermenging van die oesreste met die grond die swakste saailingontwikkeling tot gevolg gehad het. Vars en natuurlik verouderde strooi is gebruik waarvan vars strooi die nadeligste was.

Sleutelwoorde: Bewaringsbewerking, boerbone, koring, oesopbrengs, oesreste, verdigting, wisselbou.

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## LIST OF SYMBOLS AND ABBREVIATIONS

ABM	=	Above ground biomass (g/pot)
ANOVA	=	Analysis of variance
AsMec	=	Asasa mechanised
AsOx	=	Asasa ox-plow
BDWA	=	Biomass dry weight at anthesis
BURN	=	Stubble burning
BY	=	Biomass yield
C	=	Annual service cost
CIMMYT	=	International Maize and Wheat Improvement Center
CIDA	=	Canadian International Development Agency
Cm	=	Centimetre
CT	=	Conventional tillage
CS	=	Cropping sequence
CW	=	Continuous wheat
DAE	=	Days after emergence
DAP	=	Diammonium phosphate
EARO	=	Ethiopian Agricultural Research Organisation
EB	=	Ethiopian Birr
ES	=	Number of emerged seedlings/pot
FB-W	=	Faba bean-wheat
FB-W-W	=	Faba bean-wheat-wheat
GNU	=	Grain N uptake
GN%	=	Grain N%
GPS	=	Grains per spike
GY	=	Grain yield
HAR	=	Holleta Agricultural Research
HI	=	Harvest index
HT	=	Plant height in cm
IV	=	Index variability of net benefit
KuMec	=	Kulumsa mechanized
KuOx	=	Kulumsa ox plow

KPa	=	Kilo Pascal
LSD	=	List significant difference
LOC	=	Location
m <sup>-2</sup>	=	Per meter square
m a s l	=	Meter above sea level
MRR	=	Marginal rate of return
Mpa	=	Mega Pascal
MT	=	Minimum tillage
NB	=	Net benefit
n	=	The number of years
OM	=	Organic matter
<i>P</i>	=	Probability
PCM	=	Panicle count at maturity
PARM	=	Partial removal of the stubble
PR	=	Penetrometer
<i>r</i>	=	Interest rate
RBM	=	Root biomass (g/pot)
RCBD	=	Randomised complete block design
RET	=	Complete stubble retention
SD	=	Seedling density
SQRT	=	square root transformation
SPM	=	Spikes per meter squire
SNU	=	Straw N uptake
SN%	=	Straw N%
SM	=	Straw management
SY	=	Straw yield
SYS	=	System
T	=	Tillage
TBW	=	Total broadleaf weed
TCV	=	Total costs that vary
TGW	=	Total grass weed
TKW	=	Thousand kernel weight
TL	=	Total number of leaves per plant
TNU	=	Total N uptake

T/P	=	Number of tillers/plant
V	=	acquisition cost
WSB	=	Wheat seedling biomass
YR	=	Year
ZT	=	Zero tillage
$\beta$	=	Beta
$\Sigma$	=	Summation
Ca	=	Calcium
Cu	=	Copper
Fe	=	Iron
K	=	potassium
Mg	=	magnesium
Mn	=	Manganese
N	=	Nitrogen
NO <sub>3</sub>	=	Nitrate
NH <sub>4</sub>	=	Ammonium
Na	=	Sodium
P	=	Phosphorus
Zn	=	zinc

# CHAPTER 1

## INTRODUCTION

### 1.1 Statement of the Problem

#### 1.1.1 General

Ethiopia is the major producer of wheat in East Africa (>700,000 ha), accounting for over 70% of the total wheat area in the region (Hailu, 1991). The most important wheat growing areas in Ethiopia are located in the highlands (i.e., >2000 m a.s.l.) characterized by a mean annual rainfall >1000 mm with mean annual temperatures between 16 and 20°C (Hailu, 1991). Wheat is produced across a wide range of soil conditions in Ethiopia (Asnakew *et al.*, 1991).

Bread wheat (*Triticum aestivum* L.) is one of the major cereals produced in south-eastern Ethiopia (Amanuel & Tanner, 1991). Cereals, including bread wheat, occupy the largest portion of cropped land each season (Hailu *et al.*, 1990). The temperature, rainfall and altitude being especially hospitable to wheat, 75% of the total bread wheat area of Ethiopia is located in the south-eastern highlands of Ethiopia (Hailu, 1991). Currently, bread wheat production is increasing because of its significance as a cash crop, high level of production per unit area, and its role in supplying the dietary requirements of peasant farmers.

Despite the importance of the crop, bread wheat yields remain low on peasant farms. The national mean wheat yield is low having been estimated at about 1.3 t ha<sup>-1</sup> on peasant farms (Hailu *et al.*, 1990). Such low yields are attributable to both agronomic and socio-economic constraints (Hailu *et al.*, 1988). To alleviate the agronomic constraints confronting bread wheat production, it is important to examine integrated crop management practices. The combined effects of tillage and cropping sequence were previously evaluated at the Kulumsa Research Center in Ethiopia under both mechanized and ox-plow tillage systems (Asefa *et al.*, 1992). Another study conducted in south-eastern Ethiopia stressed the importance of integrating various crop production factors to improve and sustain wheat yield (Zewdu *et al.*, 1992).

A number of studies conducted elsewhere examined the effects of maintenance of crop residue and stubble burning on wheat yield and related parameters (Throckmorton, 1986; Aulakh & Gill, 1988; Rasmussen & Rohde, 1988). Maintenance of crop residue on the soil surface was considered crucial to achieving maximum yield. On the other hand, burning crop stubble, despite its long-term negative effects on the soil, imparts short-term yield advantages by reducing the effects of soil-borne diseases and weeds.

The traditional tillage system for crop production by the peasant sector in Ethiopia involves multiple passes with an ox-plow over a 3 to 4 month period prior to planting. High, often intense, rainfall may occur during this period. Reduced tillage could be an effective means of controlling soil erosion by minimizing the degree of soil disturbance, reducing the time required for seedbed preparation and enhancing crop productivity.

The primary objectives of soil tillage are to provide suitable seedbed conditions and adequate weed control (Triplett & van Doren, 1977; Lal, 1989). Unger & Cassel (1991) defined tillage as the manipulation, usually by mechanical means, of the soil characteristics and condition to enable crop production. These authors mention that tillage is done for weed control, to mix fertilizer, herbicides and plant residues into the soil, and to modify soil physical conditions for crop establishment and growth. Inversion and extensive mixing of the soil with an implement such as a mouldboard plow usually achieves this. However, excessive mechanical soil manipulation leads to deterioration of soil structure, acceleration of soil erosion and runoff, and consequently a reduction of crop yield (Aina, 1979; Phillips *et al.*, 1980; Lal, 1989). Tillage systems can also affect various soil physical and chemical properties, including soil moisture, mechanical resistance, organic matter, nitrate and ammonium.

In recent years, however, a growing awareness of sustainability issues related to soil productivity has increased interest in soil and water conservation via reduced tillage crop production systems (Phillips *et al.*, 1980; Hargrove & Hardcastle, 1984; Lal, 1989). Reduced (minimum) tillage is a form of conservation tillage in which disturbance of the soil is reduced by minimizing the degree of tillage, including only those operations that are essential. Tillage is substituted by appropriate herbicides, in order to create suitable conditions for seed germination, plant growth and weed control (Hamblin *et al.*, 1982; Triplett & van Doren, 1977).

Many studies have indicated that reduced tillage has an advantage in decreasing soil erosion and run-off and maintaining soil structure and long-term productivity (Hargrove & Hardcastle; 1984; Lal, 1989; Phillips *et al.*, 1980). The effects of conservation and conventional tillage have been evaluated in terms of minimizing production costs, safeguarding against soil loss, and boosting crop yield. Additional benefits of adopting conservation tillage are enhancement of water infiltration and increased soil organic matter contents (Triplett & van Doren, 1977; Aina, 1979; Lal, 1989; Asefa *et al.*, 1992).

Conventional tillage with heavy machinery can cause soil compaction that in turn affects root penetration (Oussible *et al.*, 1993). Compaction in the 5 to 30 cm soil depth has been observed to reduce tillering, N-accumulation and grain yield in wheat (Oussible *et al.*, 1993). However, other studies failed to demonstrate a consistent association between tillage-induced increases in penetration resistance and reduced yield of wheat (Unger & Fulton, 1990).

Several experiments tested the effects of tillage practices for wheat production on tropical highland soils (Aulakh & Gill, 1988; Asefa *et al.*, 1992; Modestus, 1994). These studies showed that wheat yields increased in response to a reduction in disruptive soil tillage.

The use of legumes in sequential cropping with wheat provides several benefits to sustainable and profitable crop production (Higgs *et al.*, 1990). In Ethiopia, a number of rotation and cropping sequence trials have indicated the importance of including dicots, particularly legumes, in the cropping system to improve yields and sustain production (Amanuel & Tanner, 1991). The benefits of such crop rotations include: N-fixation by the legume (Hargrove *et al.*, 1983); the interruption of weed (Heenan *et al.*, 1990), disease and insect cycles by dicotyledonous crops; crop diversification (Zentner & Campbell, 1988); improvement in soil tilth and a reduction in rainfall runoff and erosion (Higgs *et al.*, 1990).

Many short-term studies in the Ethiopian highlands have examined the beneficial effects of break crops on wheat production. In one study, a faba bean break crop increased wheat grain yield by 1100 kg ha<sup>-1</sup>, or 69% cf. the yield of second year continuous wheat (Hailu *et al.*, 1989). In a second study, faba bean increased the following wheat yield by 1000 kg ha<sup>-1</sup>, or 44% cf. the yield of continuous wheat (Asefa *et al.*, 1992).

However, no studies have examined the long-term integrated effects of stubble management, tillage and cropping sequence on the Ethiopian cropping environment. This study presents results generated during the 1992-2000 cropping seasons at two locations in the major wheat production zone in the south-eastern highlands of Ethiopia.

### *1.1.2 Effects on Yield and Yield Components*

Conservation cropping systems involving zero tillage and retention of crop stubble on the soil surface, have been developed in many wheat growing areas of the world. The initial interest was related to reducing cost of production, but, more recently, such efforts have focused on minimizing the degradation of soil structure and the decline in organic matter resulting from excessive cultivation (Steed *et al.*, 1993).

A problem encountered consistently in these systems across a wide range of soil types and environments has been a reduction in the early growth of wheat under direct drilling and stubble retention systems as compared with systems involving tillage and stubble burning (Reeves & Ellington, 1974; Hamblin *et al.*, 1982; Cornish & Lymbery, 1987). These authors suggested a number of causes for reduced seedling growth, including differential temperature and water content of the surface soil, reduced nutrient availability and uptake, reduced root growth, increased incidence of foliar and root diseases, and an increase of inhibitory micro-organisms and phytotoxins.

Chan *et al.* (1989) reported that the reduction in early growth on direct drilled soil could be completely overcome by soil treatments implying that biological factors were the major cause of the growth reduction. In contrast, Cornish & Lymbery (1987) concluded that reduced shoot growth was related to restricted root growth in high strength soil and was not related to biological factors or reduced uptake of water and nutrients. Fischer *et al.* (1988) reported a yield reduction with retained and incorporated stubble because of a reduction in plant density.

It has been widely accepted that in the absence of other limitations, such as diseases and nutrients (French & Schultz, 1984), water is the major factor limiting wheat yield under dryland conditions. However, there is evidence suggesting that excessive rainfall may

reduce wheat yields particularly under zero tillage and with stubble mulching (Mason & Fischer, 1986).

On the other hand, in locations where soil water availability limits plant growth, zero tillage has been reported to produce crop yields similar to (Carter & Rennie, 1985) or higher than (Braum *et al.*, 1992) conventional tillage. However, in relatively humid environments, crop yields from zero tillage systems were comparable to (Carter *et al.*, 1988) or lower than (Persons & Koehler, 1984) those obtained under conventional tillage. The poor performance of zero tillage was associated with a higher level of crop residues and cooler temperature at the soil surface (Nyborg & Malhi, 1989) and slower release of nitrate from soil organic matter (Braum *et al.*, 1992). Larson & Osborne (1985) reported that crop yields on well-drained soil appear to be the same for conservation tillage (including zero tillage), and conventional tillage, whereas such practices may decrease crop yields on poorly-drained soils.

Ayling *et al.* (1987) found that although direct drilled plots produced slightly more wheat dry matter than shallow-tined and plowed plots, only the straw fraction was significantly different, indicating that the uncultivated crop had a lower harvest index.

Rotation of cereals with legumes can alleviate yield decline by providing additional N to cereal crops through the decomposition of legume residue (Baldock & Musgrave, 1980), and by altering the physical, chemical and biological environment of the soil affecting cereal root development (Roder *et al.*, 1989).

Vyn *et al.* (1991) noted that wheat following a range of precursor crops had a significantly higher number of heads than wheat following wheat. In contrast, Ridgeman and Walters (1982) found no effect of crop rotation on head number per unit area, but noted that kernel weight was the only yield component contributing to higher yield when wheat was grown in rotation.

Badaruddin & Meyer (1989) observed increased kernel weight, test weight and total N uptake in both the grain and straw of wheat grown after legumes. Asefa *et al.* (1992) reported a marked improvement in yield components such as spike density, 1000 kernel

weight, harvest index and grains per spike of wheat grown after a faba bean precursor crop.

Wright (1990) showed that the grain yield of barley produced on faba bean residue was 33% greater than a crop grown on barley residue, and Meyer (1987) reported a 12 to 15% greater wheat yield on pulse vs. wheat residue. In Idaho, Mahler & Auld (1989) observed a 30 to 40% increase in winter wheat yield following winter pea harvested for seed. Marcellos (1984) showed an average wheat yield increase of 97% when pulses rather than wheat preceded wheat in Australia.

### *1.1.3 Effects on Nutrient Uptake*

In cereal cropping systems, the stubble from the previous season's crop must be managed. Usually it is burned or incorporated into the soil by cultivation in areas where grazing is not common. Frequency of stubble burning depends on the risk of disease and weed carry-over. Retention of stubble can help to reduce wind erosion (Marsh & Carter, 1983), structural damage from raindrop impact, and water evaporation from the soil surface. Stubble management may also affect the availability of soil or fertilizer nitrogen (N) for crop growth.

Bacon & Cooper (1985) found that stubble retention and delayed N application increased wheat growth and yield, and suggested that these effects were largely due to the impact of management practices on soil N status which in turn influenced wheat performance. Stubble management is an important determinant of both mineral N concentration and water content. Bacon (1987) stated that stubble retention resulted in a higher soil  $\text{NO}_3$  level than stubble burning, and there was a strong correlation between soil mineral N content and wheat N accumulation when the stubble had either been left undisturbed or buried several months prior to wheat sowing. The effect of stubble retention on N uptake was evidently due to increases in soil  $\text{NO}_3$  and  $\text{NH}_4$  concentration, resulting in increased wheat N accumulation at harvest. The residue effect on N uptake by wheat varied with stubble management practices. With stubble burning and retention N uptake was increased, whereas with stubble incorporation N uptake was decreased (Bacon, 1987). Some of the reduced growth and N accumulation associated with incorporation of large quantities of

residue at sowing could be due to phytotoxic stubble break-down products accumulating near the seed (Chou & Lin, 1976).

Incorporation of straw has been shown to reduce the level of inorganic N in the soil at least temporarily (Black & Reitz, 1972; Powlson *et al.*, 1985). However, some of the N immobilized by the stubble can be remobilized later in the same growing season and become available for uptake by the crop (Powlson *et al.*, 1985; Seligman *et al.*, 1986).

Altering the crop environment by eliminating tillage has been shown to influence N availability. Blevins *et al.*, (1977) found that the low yield response to N fertilizer commonly observed at lower than optimum N levels in no-till corn was the result of more total N being immobilized under zero tillage. In the zero tillage soils, organic residues collected near the surface where the rate of microbial activity increased due to the presence of an energy source and moisture (Doran, 1980). Surface residues may also increase the potential for N loss by denitrification. Rickman & Klepper (1980) reported that surface residues in a zero tillage wheat environment on a poorly-drained soil contributed to prolonged anaerobic conditions, resulting in a loss of fertilizer N and a 20% reduction in yield.

According to Christensen *et al.* (1994) wheat response to N fertilizer can vary with tillage system and soil water content. Results reported by Rao & Dao (1992) suggest that cereals under reduced tillage and zero tillage may require additional N fertilizer to reach production levels similar to conventional tillage because of a low extraction efficiency of available N. However, Campbell *et al.*, (1993) claimed that the response of continuous wheat to N fertilizer declined over time because of the increased availability of N under zero tillage supplied by an adequate amount of N fertilizer.

Blevins *et al.* (1977) reported no significant differences in extractable Ca under different tillage methods, while Triplett & van Doren (1969) showed that soil K levels in the first 5 cm of the soil were greater under no tillage. In contrast, Hargrove *et al.* (1982) reported a lower K concentration under no-tillage compared to mouldboard plow tillage.

In Indiana, Mackay *et al.*, (1987) examined P and K uptake by corn after nine years of conservation tillage. Bray-P and extractable K were evenly distributed throughout the top

soil (0-28 cm) under mouldboard plow tillage, whereas in ridge tillage and no-tillage these nutrients were stratified. Deep placement of fertilizer P and K was recommended after several years of continuous no-till cropping to provide P and K to roots growing deeper in the soil

Kitur *et al.*, (1984) evaluated the influence of no-till and mouldboard plowing on crop recovery and transformation of fertilizer N, and found that fertilizer N immobilization was greater in the surface 5 cm of no tillage soil, reducing the recovery of N fertilizer relative to the mouldboard plow treatment. It was observed that in mouldboard tilled soil fertilizer N was more uniformly distributed throughout the surface 15 cm which approximated the depth of plowing.

No-till resulted in more soil organic C and N closer to the soil surface (Doran, 1980) than conventional tillage systems. Nitrogen immobilization is enhanced and nitrification rates are diminished under no-till relative to conventional tillage (Stinner *et al.*, 1983). This often reduces NO<sub>3</sub> leaching in no-till systems (Lamb *et al.*, 1985) because it leaves less NO<sub>3</sub> in the soil profile. Lamb *et al.* (1985) observed that reducing tillage intensity decreased the loss of organic matter and total N. Havlin *et al.*, (1990) found that crop management systems that maintain surface residue under reduced tillage resulted in greater soil organic C and N which may improve soil productivity.

The beneficial residual effects of legume cultivation on the yield of a subsequent cereal crop have been demonstrated in an earlier study (Senaraine & Hardarson, 1988). This residual effect was noted whether the legumes were incorporated as green manure (Heichel, 1987), grazed by animals (Watson, 1963), harvested for hay (Papastylianou, 1987) or for grain (Blumenthal *et al.*, 1988). Thus, a beneficial residual effect is not necessarily dependent on the above-ground material being returned to the soil, although the magnitude of the yield increase of a subsequent crop is related to the amount of material returned to the soil (Heichel, 1987). A beneficial residual effect of leguminous crops should be expected when the amount of fixed N<sub>2</sub> returned by the legumes to the soil is greater than the amount of N taken up in the harvested grain (Eaglesham *et al.*, 1982).

Senaraine & Hardarson (1988) suggested that the N benefit to a subsequent crop following legumes was partly due to a lower uptake of soil N by legumes relative to cereals. This

combined with the carryover of N from the legume residue resulting in a greater uptake of soil N by the subsequent crops. The available N for a subsequent crop will be influenced by the amount of legume residues left, the availability of N from the legume residues, mineralization of soil organic matter, and the extent to which soil N was depleted by the preceding crop. Any contributions to soil N from the preceding crops would therefore be largely due to differences in N release from live or decomposing roots and nodules (Papastylianou, 1987). There is also evidence in the literature indicating that some legumes are capable of releasing significant amounts of fixed N into the root zones (Wacquart *et al.*, 1989).

The inclusion of grain legumes in cropping sequences generally increases soil nitrate-N, grain yield, total N accumulation, and N-use efficiency of the subsequent wheat crop compared with continuous wheat receiving fertilizer. One study revealed that wheat without N fertilizer, but following a legume crop, produced a yield equivalent to continuous wheat receiving 75 kg N ha<sup>-1</sup> (Badaruddin & Meyer, 1994). These results indicate that grain legumes should be considered to replace fallow and at least some N fertilizer.

#### *1.1.4 Effects on Soil Physical Properties*

The importance of soil as the medium for root growth and a source of nutrients and water has long been recognized by researchers. Well-established physical, chemical and biological factors contribute to the development and productivity of soils. The number, type and depth of pre-plant tillage may affect many soil physical properties. However, crop response to these changes in soil properties depends on length of growing season, amount of rainfall and on soil productivity (Griffith *et al.*, 1986). Thus, the effects of changes in soil properties due to tillage must be interpreted for different regions.

Soil properties that can alter in response to tillage include organic matter content, erodibility, moisture content, temperature, bulk density and aggregate size and stability (Griffith *et al.*, 1986). Tillage systems vary in the degree of soil pulverization they induce, and placement of the previous crop residue (i.e., surface incorporated or partially incorporated) often has a greater influence on these soil properties than the pulverization. Thus, residue placement preceding and during the growing season, especially the amount

remaining on the soil surface, affects accumulation of soil organic matter, soil erodibility, soil temperature and soil water (Griffith *et al.*, 1986). Soil organic matter resulting from residue decomposition affects soil aggregation and stability.

Soil cultivation has been practised for residue management, seedbed preparation and to reduce the surface compaction due to implement traffic and natural soil settling. However, tillage may also lead to the breakdown of organic matter, loss of soil water and increased susceptibility to wind and water erosion (Carefoot *et al.*, 1990). Conservation tillage systems, such as stubble mulching, zero tillage or minimum tillage, can therefore be valuable in combating soil degradation. However, concern has been expressed that zero tillage can lead to excessive soil compaction on soils with weak structure. Excessive compaction may restrict soil aeration and crop root development, restricting water uptake, nutrient availability and overall crop growth (Henderson, 1991).

Penetration resistance approximates soil compaction. Various penetration resistance studies have been conducted to correlate soil strength with plant growth and to establish the limiting penetration resistance for root growth (Ehlers *et al.*, 1983) or shoot emergence (Ball & O'Sullivan, 1982).

When a soil is placed under zero tillage management, the surface soil layer may become more compacted than under conventional tillage (Ehlers *et al.*, 1983), particularly in coarse-textured soil. However, in the deeper soil zones, compaction is generally no greater under reduced than conventional tillage systems and may be lower (Gantzer & Blake, 1978; Malhi & O'Sullivan, 1990). Malhi & O'Sullivan (1990) observed higher penetration resistance in surface soils after 5 years of zero tillage as compared to conventional tillage. Malhi *et al.* (1992) determined, after 7 years of tillage treatments, that penetration resistance in the surface 10 cm of the soil was higher under zero and minimum tillage than conventional tillage, but did not differ in the 10 to 20 cm or 20 to 30 cm depths.

Hammel (1989), working on silt loam soils, observed that bulk densities in the surface 30 cm of soil were higher under zero tillage than under minimum or conventional tillage. A tillage-induced high-density layer occurred in the conventional tillage and minimum tillage treatments at 10 to 15 cm immediately below the tillage depth. Penetration resistance was

also higher in the surface 25 cm under zero and minimum till relative to conventional tillage.

However, tillage does not consistently affect penetration resistance and bulk density as soil texture, aggregation, organic matter content and water conditions can influence the sensitivity of a soil to compaction and the persistence of the effect (Voorhees, 1987). Hill & Cruse (1985), working on clay loam and loam soils, observed increases in penetration resistance after 8 years under zero tillage compared to conventional tillage, but bulk density was not affected. Carefoot *et al.* (1990), working in the semi-arid region of Alberta, observed that bulk density did not differ in loam and clay soils which had received 3 to 8 years of zero vs. conventional tillage. Blevins *et al.*, (1983a) reported that tillage had no effect on soil bulk density (0-15 cm layer) after 10 years of continuous zero and conventional tillage in Kentucky.

However, some soil physical properties, such as bulk density, porosity, and penetration resistance which affect crop production, may be favorably or unfavourably affected by tillage (Juo & Lal, 1977; Cassel & Nelson, 1985). In the literature, the effects of tillage on soil physical properties are reported as being related to soil type, type of tillage equipment, tillage depth, soil conditions such as water content at the time of tillage, and climatic conditions.

A well-planned crop rotation system can reduce the susceptibility to soil erosion and degradation, improve soil fertility, and increase the availability of stored water in addition to other agronomic benefits. Cropping sequence or crop rotation may also influence soil strength and bulk density. McFarland *et al.*, (1990) observed that bulk density was lower in the surface 7.6 cm under a sorghum-wheat-sorghum rotation relative to a wheat-soybean rotation. They also observed that the penetrometer resistance at the 10 to 20 cm depth was greater under conventional tillage than under zero tillage, likely due to the greater amount of equipment traffic required in the conventional system.

### 1.1.5 Effects on Soil Chemical Properties

Retaining crop residues on the soil surface rather than burning or incorporating them by tillage has been shown in many studies to increase organic carbon and total nitrogen in the 5-15 cm layer of the soil (Rasmussen & Collins, 1991). These authors attributed the higher levels of carbon and nitrogen in the surface layer to slower residue decomposition and oxidation of soil C, and reduced erosion. The concentration of soil organic carbon depends on the quantity of residue retained and its rate of decomposition. Temperature, water status, aeration, pH, C, N, lignin content, residue particle size and degree of burial in the soil all influence biological decomposition (Parr & Papendick, 1978).

On the other hand, in a sandy loam soil, two years of conventional cultivation with stubble burning led to a 33% loss in organic carbon from the top 5 cm relative to direct drilling with stubble retention. This decrease could be accounted for by the increase in the 10-20 cm layer attributed to soil mixing by tillage (Chan & Mead, 1988), therefore, in this case, the loss of organic carbon from the immediate surface was due to redistribution by soil inversion. Stubble burning is often regarded as a cause of soil organic matter decline, while retention of stubble increases organic matter content of the soil (Charmen, 1982).

Tillage plays an important role in redistribution of organic matter and plant nutrients within the soil profile, while stratification is commonly observed with conservation tillage practices. The extent and rate to which this phenomena develops depends on several variables, including the type of conservation tillage, the duration of the tillage practice, soil type, crop rotation, and fertilizer management techniques.

In general, chemical constituents accumulate within the surface layer of the soil under conservation tillage. However, below a soil depth of approximately 5 to 10 cm the pattern is often reversed. Stratification of organic matter, especially under no tillage has been observed repeatedly (Blevins *et al.*, 1977; Juo & Lal, 1979; Doran, 1980; Dick, 1983). This is because under conservation tillage the majority of the crop residues are maintained on the soil surface instead of being mixed throughout the tillage layer. Additionally, plowing and secondary tillage increase the rate of organic matter loss because tillage stimulates greater microbial contact with residue and thus greater microbial activity. However, the increased microbial activity under conventional tillage continues only until

the readily available organic residue has been converted to CO<sub>2</sub> and stabilized humic compounds. The distribution of other organic constituents in no-till soil, such as organic N and P, parallels closely that of organic carbon (Dick, 1983).

Tillage was reported to have lowered the pH of the surface soil compared to direct drilled soil. It was postulated that the lower pH of the upper 5 cm was the result of soil mixing and inversion of Al from the lower layer (Chan *et al.*, 1992). Tillage practices which result in soil inversion could be potential causes of surface soil acidification for soils with highly acidic subsoils (Chan *et al.*, 1992).

Mechanical incorporation of fertilizer throughout the plow layer of the soil is not possible with no-till, and, furthermore, substantial amounts of nutrients are subsequently deposited on the soil surface as plant residues. Thus, a number of studies have shown that conversion from conventional tillage to no-till farming can significantly change the distribution of organic matter and available nutrients in the soil profile (Blevins *et al.*, 1977; Doran, 1980; Dick, 1983). The change in distribution of organic matter can also influence aggregate stability (Douglas & Goss, 1982), and this may be important since the break down of soil organic matter and consequently soil structure under conventional tillage is of concern throughout the world. Indeed, it has been suggested that the degradation of soil organic matter is less rapid under no-till than conventional tillage (Dick, 1983).

However, the plant nutrient most affected by conservation tillage is P as it is essentially immobile in the soil. Concentration of plant available P in the surface layer (0-1.25 cm) of no-till soil was reported to be eight times higher than in a similarly fertilized conventional tillage treatment (Eckert & Johnson, 1985). Kitur *et al.* (1994) reported that soil P was stratified with most P concentrated in the top 5 cm of the soil, particularly under conservation tillage systems. Increase in available P concentration at the soil surface due to conservation tillage provides an explanation for the rapid increase in soluble P losses under conservation tillage (Baker & Laflen, 1983; Romkens *et al.*, 1973). Water flowing over the surface of a conservation tillage field interacts with the P enriched layer, bringing a higher concentration of P into solution than from a conventionally tilled field. However, as Andrask *et al.* (1985) demonstrated, fertilizer management plays a key role in determining whether P loading is increased under conservation tillage regardless of the existence and extent of stratification.

Stratification of other nutrients such as K, Ca, Mg, Mn, Fe, Cu, and Zn has also been associated with the adoption of conservation tillage (Lal, 1976; Blevins *et al.*, 1983b; Shuman & Hargrove, 1985).

An important element from agricultural and environmental perspectives is N. As previously mentioned, organic N is stratified in soils to which conservation tillage has been applied. Dowdell *et al.*, (1983) found that the nitrate concentration in the soil solution was greater in a plowed field than in direct drilled plots. This difference occurred during the month immediately following fall plowing; by spring, no significant difference could be detected. The increase of nitrate concentration in the plowed field is due to increased organic N mineralization. However, Kitur *et al.* (1994) reported that  $\text{NH}_4$  and  $\text{NO}_3$  levels in the 0-5 cm layer of the soil were lower for mouldboard and no-till relative to chisel plowing. On the contrary, at the 5-15 cm depth,  $\text{NH}_4$  levels were highest for chisel plowing and lowest for zero tillage; thus, it appears that the placement of residue affected mineralization in these layers.

The maintenance of the chemical and physical fertility of many soils is dependent on the conservation of soil organic matter (Greenland, 1971). A legume-based rotation can be used to maintain soil fertility, where most of the nitrogen requirement of the crop can be provided by mineralization of organic residues (Greenland, 1971). A move to more intensive cropping is likely to increase the loss of soil organic matter and contribute to a long-term decline in fertility (Dalal & Mayer, 1986). Zhiguo Zhang & Blevins (1996) stated that rye and hairy vetch cover crops showed little influence on soil chemical properties after 10 years of production. The organic C, N, pH, extractable P, and exchangeable Ca, Mg, K in the 0 to 5 cm soil depth were not significantly different between the treatments.

### ***1.1.6 Effects on Weed Population Dynamics***

Weed management is one of the most important aspects of crop production because weeds can seriously interfere with crop yields. Weed management has been one of the most important agricultural concerns throughout history. Even with the help of herbicides, weed

control is inadequate in many cases. Crop yields can be reduced to the point of total crop failure as a consequence of aggressive weed competition. The use of cultural practices such as stubble management, tillage, and crop rotation may minimize the reduction in crop yields due to weed interference.

Stubble management effects on weeds is controversial (Rasmussen *et al.*, 1986; Rasmussen & Rohde, 1988). Some researchers indicate that stubble burning affects weed seeds in the soil, reducing the seed bank, while other reports emphasize the role of stubble retention. Some stress the importance of stubble in releasing toxic (allelopathic) chemicals that retard weed growth; these effects vary with weed species. Moreover, burning of wheat and barley stubble has been shown to destroy weed seeds above or on the soil surface; burning also increased the germination of previously dormant seeds which allowed subsequent control either by herbicide application or cultivation prior to sowing (Heenan *et al.*, 1990). Retention of stubble resulted in greater water availability and reduced maximum temperatures, encouraging the germination of weed seeds (Cheam, 1986).

Weed control is one of the main reasons for tillage. Therefore, any change in tillage will likely influence the composition of weed communities (Arshad *et al.*, 1994). Coffman and Frank (1992) suggested that the continuous use of conservation tillage might alter the composition of annual weed communities by the second or third year, especially with continuous use of the same family of herbicides. One report concluded that, in addition to herbicide, some degree of tillage is required for weed control in wheat (Hume *et al.*, 1991).

Arshad *et al.* (1994) reported that differences in the composition of weed communities induced by tillage systems varied according to the weed species. They also showed that use of either tillage or a preceding application of glyphosate did not suppress some weed species. However, their results indicated that conventional tillage and reduced tillage provided better weed control than zero tillage. Based on herbicide and tillage requirements, the reduced tillage system was more economical and environmentally desirable than conventional and zero tillage.

Crop rotation is an integral component of sustainable agriculture because it can improve soil quality, reduce disease and pest problems, and increase crop yields (Crookston *et al.*, 1991). Weed population shifts associated with changing agronomic practices are complex

and dynamic and the processes are not predictable (Blackshaw *et al.*, 1994). Changes in tillage can cause shifts in weed species and densities (Froud-Williams *et al.*, 1983). Previous studies have documented that conservation tillage can increase the density of perennial weeds and some annual grasses (Brandt, 1992). The effect of reduced tillage on annual broadleaf weeds is less clear; some species increase, but others decrease in density (Teasdale *et al.*, 1991).

Rotational use of crops and their associated herbicides can interact to affect weed species (Ball & Miller, 1990). Continuous use of a specific herbicide can lead to an increase in weeds tolerant to that herbicide and the development of genetic resistance (Hume, 1988).

According to Birhanu (1985), in the wheat-dominated regions of Ethiopia, the continuous production of wheat in rotation with barley, coupled with repeated application of phenoxy herbicides such as 2,4-D and MCPA, increased the densities of problematic grass weed species such as *Avena fatua*, *Phalaris paradoxa*, *Bromus pectinatum* and *Setaria pumila*. Freyman *et al.* (1981) also reported that with continuous application of 2,4-D, grass weeds such as *A. fatua* and *Setaria viridis* became serious problems in long-term wheat production systems.

Among the grass weeds, *Bromus* is one of the most economically important weeds constraining wheat production because of the difficulty to control *Bromus* in wheat with herbicides. *Bromus* is especially a problem under conservation tillage because the surface residue creates an ideal niche for grassy annual weed establishment (Thill *et al.*, 1984). *Bromus* is also a serious problem weed in wheat under continuous cropping and reduced tillage (Dao, 1987). The adoption of conservation tillage for wheat production has favoured the growth and spread of *Bromus*.

Adoption of conservation tillage systems is to some extent inhibited by real and perceived weed control problems. Greater reliance on herbicides is sometimes ineffective, uneconomical and perhaps environmentally undesirable. Most studies show that crop rotation, tillage and herbicides can have a large impact on weed population (Froud-Williams *et al.*, 1983). Adoption of conservation tillage systems may be more successful if carefully planned to incorporate a varied crop rotation with properly used herbicides that are effective against the predominant weeds, (Blackshaw *et al.*, 1994).

Crop rotation establishes the framework for sustainable weed management. Crop rotation will not eliminate the interference by weeds, but it can limit the build up of weed populations and prevent major shifts in weed species composition (Liebman & Janke, 1990). By growing a sequence of crops that differ in planting and maturation dates, competitive characteristics, and soil management requirements, the growth and reproduction of a given weed species can be disrupted. Crop rotation in conventional farming systems implies rotating both crops and herbicides, but significant effects on weed growth can still be attributed directly to tillage and soil disturbance patterns and to interference from the crops (Walker & Buchanan, 1982). Asefa *et al.* (1992), in a study of the integrated effects of tillage practices and cropping sequences on wheat production in south-eastern Ethiopia, noted a differential effect of precursor crops on weed densities. A faba bean break crop reduced broadleaf and grass weed seedling densities in the subsequent wheat crop. Walker & Buchanan (1982) reported that a corn-wheat-soybean rotation exhibited more stable weed community dynamics than did continuous monocultures of the respective crops. They concluded that the continuous monoculture practice provided maximum opportunities for the best-adapted weed species to increase, while crop rotation limited these opportunities.

### 1.1.7 Effects on Root Diseases

Conservation tillage commonly involves the retention of stubble residues on the soil surface, as a result of a reduction in the number of tillage operations. Combining these practices has the potential to reduce the risk of soil erosion and increase water infiltration and storage (Harte & Armstrong, 1983). However, the potential benefits of soil and water conservation resulting from the retention of stubble residues on the soil surface have not always resulted in higher crop yields (Felton *et al.*, 1987). This lack of yield response has been attributed to problems associated with crop establishment, crop nutrition, and an increase in crop pests and diseases, all of which can be related to the retention of crop residue on the soil surface (Felton *et al.*, 1987).

Take-all, caused by *Gaeumannomyces graminis* var. *tritici*, is the most important root disease of wheat. Eyespot, caused by the stem pathogen *Tapesia yallundae* (telomorph

stage of *Psuedocercospora herpotrichoides*), is also an important disease of wheat in many areas of wheat growing regions of the world.

The host range of the take-all fungus is limited to wheat, barley and related species of grass. This pathogen is totally dependent for its survival on an invasion of roots and tiller bases while these tissues are still alive. However, whereas wheat is very susceptible, allowing the pathogen to infect both tiller bases and roots, barley is more resistant and the pathogen is mostly restricted to the crop roots. The crop residue remains of roots decompose faster than tiller remains; the pathogen can, therefore, survive longer in tiller residue than in old roots between susceptible crops (Cook & Veseth, 1991).

Reports on the effects of either retaining or burning stubble on take-all vary. Burning stubble prior to sowing did not affect the incidence of take-all in continuously-cropped, direct-drilled wheat in north-eastern Victoria (de Boer *et al.*, 1992), but reduced the level of disease in wheat sown after lupins in southern New South Wales (Murray *et al.*, 1991). In the UK and Denmark, burning stubble prior to cultivation did not affect the incidence of take-all compared with plowing under the stubble (Slope *et al.*, 1970). Kollmorgen *et al.* (1987) reported that stubble mulches reduced the survival of take-all in buried straw in the Wimmera region of Victoria, and suggested that mulching may reduce the carry-over of the fungus.

*Tapesia yallundae* survives between crops on plant residues, particularly on old stubble (de Boer *et al.*, 1993). The removal of straw by burning would, therefore, be expected to reduce the incidence of eyespot. There are few reports on the effects of burning stubble *per se* on this disease. However, the disease was reported to be more prevalent where residues were either retained on the surface or incorporated in the soil (Murray *et al.*, 1991), or was unaffected by burning prior to plowing compared with incorporation of stubble into the soil by ploughing (Slope *et al.*, 1970). Cook & Waldher (1977) found the disease incidence to be no higher with an uncultivated mulch than with mouldboard plowing. Yarham & Hirst (1975) reported variable results in that direct drilling either increased or had no effect on the incidence of eyespot compared with plowing. Herrman & Wiese (1985) found that the disease was most common in plowed plots, intermediate in minimum-tilled plots, and the least common in uncultivated plots. However, de Boer *et al.* (1993) stated that the highest incidence of eyespot was associated with stubble retention in

continuously-cropped, direct-drilled wheat. Burning of wheat stubble, on the other hand, reduced the incidence of the disease in the uncultivated plots to negligible levels, but did not eliminate the disease. The results showed that the conventional practice of burning stubble and cultivating the soil prior to sowing can result in eyespot levels as high as those in wheat sown directly into stubble, presumably because cultivation brings old infected plant debris to the soil surface.

Scott (1969) reported that cultivation immediately after harvest significantly reduced the number of white heads caused by take-all in a subsequent wheat crop, as compared with later cultivation. He concluded that this was probably due to enhanced microbial activity and greater competition for nitrogen in the well-aerated mixture of soil and stubble. Moore & Cook (1984) found that the best take-all control in consecutive crops of wheat was achieved by thorough tillage, beginning as soon as possible after harvest. Ferraz (1979), in attempting to explain a lower severity of take-all with simulated plowing than with simulated direct drilling, suggested that early loosening of the plowed soil promoted faster disappearance of the take-all fungus than did the more compact soil in containers where seed was direct-drilled. In addition, more inoculum occurs near the crown zone in no-tilled soil, whereas the inoculum in tilled soil is more scattered and (diluted) throughout the tillage zone.

Cropping sequences and tillage practices each may influence the inoculum density of residue-borne pathogens (Sutton & Vyn, 1990). Production of wheat in sequence with non-host crops may suppress wheat pathogens by allowing more time for the organism populations to decline by modifying the residue microclimate, or through other effects (Sutton & Vyn, 1990). Tillage practices that maintain crop residues on the soil surface tend to favour the survival of pathogens, whereas burial of residues is known to favour rapid decline and block dispersal of several important wheat pathogens. Sutton & Vyn (1990) also found that cropping sequence and tillage differentially affected the severity of several important wheat diseases caused by residue-borne pathogens. de Boer *et al.* (1993) reported that rotation of wheat with leguminous crops prevented the build up of a high level of take-all and eyespot relative to continuously cropped wheat.

## 1.2 Background of the Study

Wheat is one of the major cereal crops grown in Ethiopia and is mainly grown by subsistence farmers under rainfed conditions in the highland altitude zone. In recent years, bread wheat (*Triticum aestivum* L.) has become the most important and widely cultivated food grain in the south-eastern highlands of Ethiopia. Because of higher yields from improved cultivars and a relatively favourable market price for wheat, farmers in some areas practice continuous cultivation of wheat after wheat. Continuous cultivation of wheat may result in several disadvantages among which a build up of pathogens, an increase in grass weed populations, and depletion of soil fertility over time are the major ones. In contrast, results of crop rotation experiments indicate that sowing wheat after faba bean gave significantly higher grain yields (Amanuel & Tanner, 1991). Faba bean as a precursor crop also reduces both grass and broadleaf weed densities in the subsequent wheat crop (Asefa *et al.*, 1992).

Burning of crop residues is practiced by state farms and some peasant farmers prior to the onset of rainfall to facilitate tillage operations as well as to reduce weed infestations in subsequent crops. Research indicated that stubble burning reduces the density of *Bromus* spp. and also destroys the seed of *Avena fatua* (Heenan *et al.*, 1990). It is also believed that burning may destroy disease propagules and insects harboured by crop residues. On other hand, incorporation or retention of crop residue has certain advantages, such as the build up of soil organic matter, water conservation, and erosion control.

With the help of modern herbicide technologies, it has been found possible to minimize tillage operations without affecting crop yields. An experiment conducted in south-eastern Ethiopia in 1990 on a peasant farmer's field found no significant difference in the grain yield of wheat obtained under conventional tillage, either tractor or ox-plow based, and minimum tillage where a total weed killer (i.e., glyphosate) was used under minimum tillage to control vegetation prior to sowing of wheat (Asefa *et al.*, 1992). Therefore, because of the shortage of feed for oxen particularly during the dry season, and due to constraints of fuel and spare parts for mechanized farming, economic tillage practices integrated with cropping sequence and straw management need to be investigated for applicability by the wheat farmers in the highlands of Ethiopia.

### **1.3 Objective of the Study**

The principal objective of the experiment was to determine the integrated effects of cropping sequence, straw management and tillage practices on the productivity and sustainability of wheat-based farming systems in Ethiopia.

## CHAPTER 2

### MATERIALS AND METHODS

#### 2.1 Experimental Sites

Four crop management trials were initiated during 1992 at the Kulumsa (8°02'N and 39°10'E) and Asasa (7°08'N and 39°13'E) research stations located in the south-eastern highlands of Ethiopia at altitudes of 2200 and 2360 m a.s.l., respectively. During the main crop growing season (i.e., June to November), long-term mean monthly minimum and maximum temperatures are 10.6 and 22.1 °C at Kulumsa and 6.7 and 22.7 °C at Asasa; mean precipitation during the main growing season is 504 mm at Kulumsa and 472 mm at Asasa. Kulumsa is located on a clay soil (an intergrade between an eutric Nitisol and a luvisc Phaeozem). The Asasa soil is a clay loam (calcic Chernozem). Chemical and texture characteristics of the soil profile at each station are given in Table 2.1.

#### 2.2 Experimental Methods

The four trials were conducted in pairs at each site, one mechanised and one ox-plow at each of Kulumsa and Asasa.

Each mechanised trial consisted of 12 treatments comprising the complete factorial combinations of:

- a) three levels of post-harvest straw management (SM) (i.e., burning of stubble, partial (>50%) removal of stubble, and complete retention of stubble);
- b) two levels of tillage (i.e., zero tillage (ZT) at Kulumsa and minimum tillage (MT) at Asasa vs. conventional tillage (CT) at each site), and;
- c) two levels of cropping sequence (CS) (i.e., continuous bread wheat vs. a rotation of one year of faba bean (*Vicia faba*) followed by two years of bread wheat).

The ox-plow trials omitted complete stubble retention as a SM treatment. Thus, each ox-plow trial consisted of eight treatments comprising the complete factorial combination of:

1. two levels of post-harvest SM (i.e., burning of stubble, and partial (>50%) removal of stubble);
2. two levels of tillage (i.e., MT vs. conventional tillage) and;

3. two levels of CS (i.e., continuous bread wheat vs. a rotation of one year of faba bean followed by two years of wheat).

**Table 2.1. Soil profile characteristics at Kulumsa and Asasa research stations (1992)**

	Horizon	Depth (cm)	pH (H <sub>2</sub> O)	P (ppm)	Total N (%)	Sand (%)	Silt (%)	Clay (%)
Kulumsa	A	0-10	6.1	28	0.256	18.6	32.9	48.5
		10-20	5.9	28	0.252	17.7	35.1	47.2
		20-30	6.2	27	0.214	19.2	31.7	49.1
		30-40	6.0	26	0.204	11.6	34.8	55.6
		40-50	6.5	21	0.176	15.5	38.1	46.4
	B	50-60	6.7	24	0.154	14.7	39.4	45.9
		60-70	6.6	22	0.143	18.7	36.8	45.1
		70-80	6.9	20	0.121	18.0	33.2	40.8
		80-90	6.9	14	0.118	19.2	37.3	42.8
		90-100	7.1	16	0.101	20.5	42.1	37.4
		100-110	7.0	16	0.121	17.2	42.8	40.6
	C	110-120	7.2	14	0.111	15.5	47.1	38.4
Asasa	A	0-10	6.4	32	0.208	24.0	37.2	32.8
		10-20	6.2	28	0.201	18.7	41.2	40.0
		20-30	6.7	40	0.202	22.8	40.6	36.6
		30-40	7.2	48	0.182	24.5	36.7	39.2
		40-50	7.0	32	0.167	28.7	31.5	39.8
		50-60	7.6	31	0.160	25.1	39.3	35.6
		60-70	7.8	33	0.121	33.3	37.8	18.9
		>70	7.5	31	----	48.1	37.7	14.2

P = Mehlich P analysis.

For each trial, all treatments were laid out in a split-split-plot arrangement in a randomized complete block design (RCBD) with three replications. SM treatments were initiated in main plots of 20 x 20 m, tillage in sub-plots of 10 x 20 m, and CS in sub-sub-plots of 5 x 20 m in 1992. All treatments were applied to permanent plots maintained over the trial duration.

In the mechanised trials at both locations, conventional tillage consisted of one pass with a tractor-drawn disc plow followed by two passes with a disc harrow (i.e., spaced over the "short rains" fallow period in order to maximise the control of emerging weed seedlings). For the mechanised trial at Kulumsa, a tractor-drawn Aitchison Seedmatic 3000 zero till drill was used to sow seed plus basal fertiliser for the conventional tillage and ZT treatments. In the mechanised trial at Asasa, one pass with a disk harrow was used to incorporate broadcast seed and fertiliser for the MT and conventional tillage treatments.

In the ox-plow system at both sites, conventional tillage consisted of four plowings prior to sowing (i.e., farmers' practice); for MT, one pass with the ox-plow was used to incorporate broadcast seed and fertiliser.

For the MT and ZT treatments in the mechanised and ox-plow trials, chemical fallow was practised during the "short rains" period each year. Glyphosate was spray applied at 720 g a.i. ha<sup>-1</sup> during the fallow period with a maximum of two applications per season (i.e., as required to prevent weeds from attaining a height of 20 cm).

Partial straw removal simulated grazing (i.e., approximately 500 kg ha<sup>-1</sup> of stubble remained on the surface at sowing). Straw burning was carried out during late January each year (i.e., before the "short rains" began) and plots with complete stubble retention (i.e., >2 t ha<sup>-1</sup> of stubble remaining on the soil surface at sowing) were left undisturbed until spraying or tillage operations began.

Recommended cultural practices (i.e., for non-experimental crop management factors) were adopted for bread wheat and faba bean during the trial duration. Over the period from 1992 to 2000, the trials were sown on dates ranging from June 11 to 19 at Asasa and from June 22 to July 7 at Kulumsa. Bread wheat cultivars Enkoy (1992-93), Mitike (1994), and Qubsa (1995-2000) were sown at a seed rate of 150 kg ha<sup>-1</sup>. From 1992-94, bread wheat received a basal N application of 41 kg ha<sup>-1</sup> at Kulumsa and 18 kg ha<sup>-1</sup> at Asasa. From 1995-2000, bread wheat received a basal N application of 82 kg ha<sup>-1</sup> at Kulumsa and 41 kg ha<sup>-1</sup> at Asasa. During 1992, 1995, and 1998, faba bean cultivar CS20DK was sown at a seed rate of 200 kg ha<sup>-1</sup> and basal N was applied at a rate of 18 kg ha<sup>-1</sup> at both Kulumsa and Asasa. Both crops received a basal application of 46 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> each year. Due to the risk of damage by spray drift, hand weeding was used to control weeds during years in

which both wheat and faba bean were sown (i.e., 1992, 1995, and 1998). During years in which all plots were sown to wheat, weed control entailed a post-emergence spray application of a tank mix of fenoxaprop-p-ethyl + fluroxypyr + MCPA at 0.069 + 0.175 + 1.0 kg a.i. ha<sup>-1</sup>, respectively.

## 2.3 Measurements in Field Trials

### 2.3.1 Agronomic Data

Data on various crop parameters were collected throughout the cropping season. Data on seedling density, seedling biomass, crop heading, flowering dates and maturity dates, plant height, and spikes m<sup>-2</sup> were collected from sub-sub-plots. A 9 m<sup>2</sup> area was harvested by sickle from each sub-sub-plot for the determination of grain and biomass yield, harvest index, thousand grain weight and % grain moisture. The number of grains per spike was calculated from the measured yield components.

#### 2.3.1.1 Statistical analysis

Data were analysed by individual year for all parameters included in the study. Analysis of variance (ANOVA) was calculated separately for each trial and combining data across six years. For significant factor interactions, interaction means were separated by the LSD test at the  $P=0.05$  level.

### 2.3.2 Crop Nutrient Uptake

Grain and straw N contents were determined for each sub-sub plot in 1996, 1997, 1998 and 1999 by micro-Kjeldahl analysis of grain and straw from the oven-dried samples. Grain nitrogen uptake (GNU) and straw nitrogen uptake (SNU) values were calculated by multiplying grain and straw yields by the respective N contents. Total N uptake (TNU) was calculated as the sum of GNU and SNU.

### **2.3.2.1 Statistical analysis**

The nitrogen contents of wheat grain and straw were subjected to statistical analysis using analysis of variance (ANOVA) separately for each trial, and combining data across the three years. For the significant factor interactions, interaction means were separated by the LSD test at the  $P=0.05$  level.

### **2.3.3 Soil Physical Properties**

Measurements of soil penetrometer resistance (PR) were taken manually, at the mid-tillering stage of the wheat crop, in 1994, 1996, 1997, 1998, and 1999, using a sliding cone penetrometer (Proving Ring Penetrometer Cn-970, Soiltest, Inc.) with a conical area of 24.68 cm<sup>2</sup> and a base area of 6.342 cm<sup>2</sup>. PR values were measured only at Kulumsa in 1994, and at both sites in the subsequent years. The PR values were recorded on a sub-sub-plot basis at 5 cm intervals from the soil surface to a depth of 30 cm. The readings in pounds m<sup>-2</sup> were converted to kPa by applying a conversion factor of 6.895.

#### **2.3.3.1 Statistical analysis**

PR data were log<sub>10</sub> transformed (Busscher & Sojka, 1990) before analysis. The transformed soil PR data were subjected to analysis of variance (ANOVA) for each individual trial, using MSTATC software. For the ANOVA, measurement depth was taken as a sub-factor within cropping sequence.

To effectively combine the PR data collected from the 18 site-season combinations included in the current study, mean wheat grain yields for each treatment within each trial were simultaneously regressed on log<sub>10</sub> transformed PR means for six depth intervals (i.e., 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm below the surface), across five years (i.e., 1994, 1996, 1997, 1998, and 1999), two locations (i.e., Kulumsa and Asasa), and two crop production systems (i.e., ox-plow and mechanised). Indicator variables were used to represent years, locations, and production systems (Neter *et al.*, 1990). Thus, the multiple regression analysis conformed to a model with six quantitative variables for PR, five classes (i.e., four indicator variables) representing year, and two classes (i.e., one indicator variable) for each of the qualitative variables representing location and production system.

The fitted regression equation was:

$$GY_i = \beta_0 + \beta_1 PR_{1i} + \beta_2 PR_{2i} + \beta_3 PR_{3i} + \beta_4 PR_{4i} + \beta_5 PR_{5i} + \beta_6 PR_{6i} + \beta_7 YR_{1i} + \beta_8 YR_{2i} + \beta_9 YR_{3i} + \beta_{10} YR_{4i} + \beta_{11} LOC_i + \beta_{12} SYS_i + \epsilon_i$$

$$i = 1, 2, \dots, N$$

where  $GY_i$  = expected grain yield ( $\text{kg ha}^{-1}$ ) of the  $i^{\text{th}}$  treatment mean

$N$  = number of treatment means (= 180 in this study)

$\beta_0$  = constant

$PR_{1i}$  = PR ( $\log_{10}$  transformed) at 0-5 cm depth

$PR_{2i}$  = PR ( $\log_{10}$  transformed) at 5-10 cm depth

$PR_{3i}$  = PR ( $\log_{10}$  transformed) at 10-15 cm depth

$PR_{4i}$  = PR ( $\log_{10}$  transformed) at 15-20 cm depth

$PR_{5i}$  = PR ( $\log_{10}$  transformed) at 20-25 cm depth

$PR_{6i}$  = PR ( $\log_{10}$  transformed) at 25-30 cm depth

$YR_{1i}$  = indicator variable for 1994 (1 if 1994, 0 otherwise)

$YR_{2i}$  = indicator variable for 1997 (1 if 1997, 0 otherwise)

$YR_{3i}$  = indicator variable for 1998 (1 if 1998, 0 otherwise)

$YR_{4i}$  = indicator variable for 1999 (1 if 1999, 0 otherwise)

$LOC_i$  = indicator variable for location (1 if Asasa, 0 if Kulumsa)

$SYS_i$  = indicator variable for system (1 if mechanised, 0 if ox-plow)

$\epsilon_i$  = error term.

The multiple regression analysis initially included all 12 components. An iterative process was adopted, sequentially eliminating components exhibiting the least contribution to the regression sum of squares and being non-significant individually ( $P > 0.05$ ). Ultimately, only those components with significant ( $P < 0.05$ ) contributions to the multiple regression were retained in the regression model (Neter *et al.*, 1990).

### 2.3.4 Soil Chemical Properties

To determine the effects of treatments on soil chemical properties, samples were taken prior to planting and post-harvest of wheat in 1996, 1997, 1998 and 1999 from Kulumsa and Asasa for organic matter content (0-5 cm) and pre-planting for  $\text{NO}_3$ ,  $\text{NH}_4$ , pH and P at three different depths (0-15, 15-30 and 30-60 cm). Samples were analysed for soil OM (Walkley & Black, 1947),  $\text{NO}_3$  (2 M KCl),  $\text{NH}_4$  (2 M KCl) (Bremner, 1965), pH (water). P

content was determined by the method of Mehlich *et al.* (1962) for 1996-97 samples and by the Olsen (1953) method for 1998-99 samples. Starting from 1998, determinations of K (Morgan, 1921) and Zn (Emmel & Stotera, 1977) content were carried out for the 0-15, 15-30 and 30-60 cm soil depths for all locations. Determination of K was measured using a flame photometer and Zn was measured by spectrophotometer.

#### **2.3.4.1 Statistical analysis**

All soil chemical data were subjected to analysis of variance (ANOVA) separately for each trial, and also combining data across years for each parameter. For significant factor interactions, interaction means were separated by the LSD test at the  $P=0.05$  level.

#### **2.3.5 Weed Assessment**

Weed count data (no.  $m^{-2}$ ) were collected each year at each location 30-35 days after crop emergence and prior to the first hand weeding or herbicide application. Four counts of 0.25  $m^2$  each using metal quadrats were taken from each plot resulting in a total sample area of 1  $m^2$ . All weeds within the quadrat were uprooted and separated into the different species and counted. Depending on weather conditions and weed populations, grass weed panicle counts were taken at maturity of the wheat crop for the major grass weed species.

##### **2.3.5.1 Statistical analysis**

The weed count data were transformed using a square root transformation of actual data (i.e.,  $\text{SQRT}[\text{weed count } m^{-2} + 0.5]$ ) to satisfy the assumptions of normality of distribution and homogeneous variances. The adjustment constant of 0.5 was used for count data to compensate for the 0 values (i.e., when a weed species is absent from a given plot). The transformed weed density data were subjected to analysis of variance separately for each trial. For the significant factor interactions, interaction means were separated by the LSD test at the  $P=0.05$  level.

#### **2.3.6 Root Disease Assessment**

The incidence of take-all and eyespot was estimated during 1994, 1996, 1997 and 1999 within each sub-sub-plot in each trial. Each season, samples of main stems and tillers were

collected for disease assessment immediately after harvest. Samples were collected by traversing a "W" pattern across each sub-sub-plot. After washing and drying the stubble samples, a minimum of 80 crowns from each sub-sub-plot were assessed for disease symptoms.

Eyespot severity was assessed using the 0-3 rating scale of Scott & Hollins (1974) in which 0 = crowns with no infection, 1 = slight infection, 2 = moderate infection, and 3 = severe infection. If eyespot lesions were not clearly visible, the internodes were split and checked for internal growth of the typical greyish, cottony mycelium to confirm the presence of the disease. The number of crowns in each severity class was recorded, and a weighted percent severity score for eyespot was calculated for each sub-sub-plot using the following formula:  $(100 \times \sum([\text{number of crowns in each severity class}] \times [\text{the severity class rating}])) \div ([\text{total number of crowns scored}] \times 3)$ .

Take-all severity was assessed on the same sampled crowns using the 0-5 rating scale of Scott (1969) in which 0 = crowns with no infection, and 5 = severe infection. A weighted percent severity score for take-all was calculated for each sub-sub-plot using the following formula:  $(100 \times \sum([\text{number of crowns in each severity class}] \times [\text{the severity class rating}])) \div ([\text{total number of crowns scored}] \times 5)$ .

### *2.3.6.1 Statistical analysis*

Weighted disease severity scores were subjected to statistical analysis subsequent to data transformation comprising square root of (weighted percent severity score + 0.5). For both diseases, analyses of variance (ANOVA) were calculated separately for each trial, combining data across four years. For significant factor interactions, interaction means were placed in significance groupings on the basis of the LSD test at the  $P=0.05$  level.

For each of the 16 site-season combinations included in the study (i.e., four trials by four years), simple pair-wise correlations were calculated among grain yields, and take-all and eyespot scores on a sub-sub-plot basis.

## 2.4 Pot Experiment

The pot experiment was conducted at the Kulumsa research station in a lath house using soils collected from the Kulumsa and Asasa sites.

### 2.4.1 *Experimental Methods*

The 13 treatments consisted of a control (i.e., no straw added) plus the full set of factorial combinations of three levels of straw management (i.e., burning, incorporation and surface retention), two types of straw (i.e., naturally degraded vs. fresh straw), and two rates of straw application (i.e., 0.8 and 2.5 t ha<sup>-1</sup>), and were laid out in a RCBD. The pot trials were conducted in three separate runs during 1999 and 2000. The bread wheat cultivar used in the pot experiment was HAR 1685 (Qubsa) at the rate of 10 seeds pot<sup>-1</sup>. The recommended rate of fertiliser for each site was applied to each soil.

### 2.4.2 *Agronomic Data*

Data was collected on the following crop parameters during the forty days following seedling emergence: number of emerged seedlings, above-ground biomass dry weight, number of tillers, plant height, and root biomass dry weight.

### 2.4.3 *Plant Tissue Analysis*

Plant analysis was conducted to determine nutrient concentrations in the seedlings using the appropriate methodologies.

### 2.4.4 *Statistical Analysis*

All data were subjected to analysis of variance (ANOVA) separately for each soil type, and combining data across the three runs. For significant factor interactions, interaction means were separated by the LSD test at the  $P=0.05$  level. The control treatments were analysed as satellite treatments, the mean of the control was compared by orthogonal contrast with the means of the straw treatments.

## 2.5 Partial Budget Analysis

Grain and straw yield data for the mechanised and ox-plow trials at Kulumsa and Asasa (i.e., 12 treatment combinations for the mechanised trials and eight treatment combinations for the ox-plow trials at both locations) were subjected to partial budget analysis (CIMMYT, 1988). Grain yields were adjusted downwards by 10%. Field prices used in the analysis were collected from local markets during the period from November to December 2000, and were adjusted for the cost of threshing (Asefa *et al.*, 2000). Thus, the field prices used for grain were 1.241 and 1.288 Ethiopian Birr (EB)/kg at Kulumsa and 1.04 and 1.169 EB/kg at Asasa for faba bean and wheat, respectively. Wheat straw was valued at 0.18 EB/kg for both locations, while faba bean stubble was assumed to have no economic value. Straw recovery rates were estimated at 50% for the burn and complete retention SM treatments, and 75% for the partial removal SM treatment. Partial budget analyses were conducted for each trial with and without the inclusion of the market value for wheat straw.

All inputs used over the trial duration were priced at the market levels during 2000. Seed for planting was valued at the year 2000 farm-gate price of grain. The cost of hand weeding and hand harvesting the two crops was estimated at 272.00 and 259.50 EB/ha for faba bean and wheat, respectively (Asefa *et al.*, 2000). During the years in which all plots were sown to wheat, in-crop chemical weed control cost 563.9 EB/ha. The cost of implementing the SM treatments was estimated as 17.5 EB/ha and 100 EB/ha for burn and partial removal of the straw, respectively, while no cost was incurred for complete retention of straw. Fertiliser costs were derived from the purchase price of fertiliser in Asela town (i.e., near Kulumsa) and Asasa district during the 2000 planting season as follows: 165.00 EB/100 kg of urea and 255.40 EB/100 kg of DAP in Asela town and 180.00 EB/100 kg of urea and 265.75 EB/100 kg of DAP in Asasa district.

The annual service cost (C) of the Aitchison zero-till seed drill implement used in the Kulumsa mechanised trial was based on the following formula (Spencer *et al.*, 1979):

$$C = rV [1 - (1 + r)^{-n}]$$

where  $r$  = interest rate (assumed in this analysis to be 12% per year),

$n$  = the number of years of effective use of the drill (assumed to be 5 years), and

$V$  = acquisition cost (actual US\$7785).

Based on operating efficiency data obtained from seed industry farms near Kulumsa, it was estimated that the zero-till seed drill could service 250 ha per year. Thus, the per ha annual service cost of the implement was 8.64 US\$/ha which is equivalent to 71.7 EB/ha [i.e., 8.30 EB = 1 US\$ during January 2001].

The costs of tillage and fallow season weed control in the Kulumsa mechanised trial were calculated from the frequency of operations at Kulumsa (Appendix 9.1) and the following operational costs: first plowing 215 EB/ha, second plowing 150 EB/ha, disk harrowing 90 EB/ha, seeding by conventional drill 47 EB/ha, seeding by ZT drill 71.7 EB/ha, and weed control during the fallow season with Roundup costing 92 EB/l of product plus 10 EB/ha per spray application.

The costs of tillage and fallow season weed control in the Asasa mechanised trial were calculated from the frequency of operations at Asasa (Appendix 9.2) and the following operational costs: first plowing 200 EB/ha, second plowing 75 EB/ha, disk harrowing 70 EB/ha, cost of broadcasting seed and covering by disk harrow 70 EB/ha, and weed control during the fallow season with Roundup costing 92 EB/l of product plus 10 EB/ha per spray application.

For the ox-plow trials at Kulumsa and Asasa, conventional tillage costs were estimated as 300 EB/ha and 500 EB/ha for Kulumsa and Asasa, respectively (i.e., 5 passes with the ox-plow at 60 and 100 EB/ha/pass, respectively); the corresponding cost of the minimum tillage treatment at each location consisted of the cost of one pass with the ox-plow (i.e., to cover the broadcast seed and fertiliser), and the cost of weed control during the fallow season with Roundup costing 92 EB/l of product plus 10 EB/ha per spray application. Roundup was applied at the same frequencies and rates as in the corresponding mechanised trials (Appendices 9.1 and 9.2).

Treatments were ranked in order of ascending Total Costs that Vary (TCV), and dominance analysis was used to eliminate those treatments costing more but producing a lower Net Benefit (NB) than the next lowest cost treatment. The marginal rate of return (MRR) was calculated for each treatment relative to the next lowest cost, non-dominated treatment (i.e., treatments were considered to be dominated if they failed to exhibit an MRR >100% relative to the next lowest cost treatment).

## CHAPTER 3

### EFFECTS OF TREATMENTS ON CROP YIELDS AND YIELD COMPONENTS

#### 3.1 Introduction

In the highlands of south-eastern Ethiopia, bread wheat is one of the most important cereal crops (Amanuel & Tanner, 1991). Over the past three decades, the production of bread wheat has increased due to the release of high yielding and well-adapted varieties for the region. Nonetheless, the mean grain yield of bread wheat in Ethiopia is low due to several constraining crop management factors, including:

- a low rate of adoption of improved wheat cultivars by the small-scale farming sector (i.e., the sector responsible for the majority of Ethiopia's wheat production);
- the prevalence of unimproved farming practices including hand weeding of wheat - a problem exacerbated by the limited availability of herbicides for purchase by peasant farmers in Ethiopia; and
- depleted soil fertility and a low level of fertiliser usage - in particular, nitrogen (N) deficiency is often encountered in wheat crops growing in the cool, wet highlands of Ethiopia (i.e., >2200 m a.s.l.) or on the frequently waterlogged highland Vertisols (Tanner *et al.*, 1993).

To overcome these constraints which hinder the production of bread wheat, it is important to examine the effects of various crop management factors on wheat yield and yield components. The effects of the maintenance of crop residues vs. stubble burning on wheat yield and related factors have been studied by several authors (Aulakh & Gill, 1988; Rasmussen & Rohde, 1988). Maintenance of crop residues on the soil surface is considered to contribute to high crop yields and an improved soil nutrient content, resulting in increased crop nutrient uptake.

Soil physical and chemical properties, including soil moisture level, mechanical resistance, organic matter, nitrate, and ammonium contents, are affected by tillage practices. As the frequency of tillage is increased, soil structure deteriorates and erosion is exacerbated.

Reduced tillage can minimise such deleterious effects on soil properties (Stobbe, 1990). Thus, the implementation of conservation tillage is widely considered to be essential for the maintenance, restoration and/or improvement of the sustainable production base of most arable crop production systems. This is certainly true for highly erodible areas under annual crop production and for other potentially fragile cropping systems where soil physical, chemical and biological parameters appear to be deteriorating (Phillips *et al.*, 1980). Conservation tillage research and implementation has mostly been focused on rainfed production systems where crop residue retention enhances both erosion control and soil water retention. Under cool, high precipitation, rainfed conditions, however, the retention of crop residues can aggravate crop stand establishment and facilitate disease development if the residues are not managed properly and/or if proper crop rotations are not followed.

The effects of minimum tillage on wheat production systems have been evaluated in terms of multiple benefits; minimum tillage can reduce the cost of production, control soil erosion, and increase the yield of bread wheat. Conservation or minimum tillage practices have been recommended not only due to a biological yield advantage, but for other merits associated with bread wheat production (Modestus, 1992).

The inclusion of legumes in sequential cropping with wheat contributes to sustainable and improved crop production (Higgs *et al.*, 1990). Rotation of cereals with legumes can alleviate yield decline by providing additional N to cereal crops through the decomposition of legume residue (Baldock & Musgrave, 1990), and by altering the physical, chemical and biological environment of the soil.

In the south-eastern highlands of Ethiopia, no previous study examined the integrated effects of stubble management, tillage and cropping sequence on wheat crop performance. Therefore, this study was initiated to examine the long-term effects of such crop management factors on wheat yield and yield components.

## **3.2 Results and Discussion**

### **3.2.1 Grain yield**

#### **3.2.1.1 Straw management effect**

Crop grain yield was significantly affected by straw management (SM) in the mechanised trial at Kulumsa during 1994, 1996, 1997 and 2000, in the mechanised trial at Asasa during 1993, 1995 (in both wheat and faba bean), 1996, 1998 (in wheat only), 1999 and 2000, in the ox-plow trial at Kulumsa during 1995 (in wheat only), 1998 (in faba bean only) and 2000, and in the ox-plow trial at Asasa during 1994, 1996, 1999 and 2000 (Table 3.1). In the seven instances of a significant effect of SM on grain yield in the ox-plow trials, the stubble burning (BURN) treatment was consistently superior to partial removal of stubble (PARM). In the 11 instances of SM effect in the mechanised trials, BURN was superior to one or both of PARM and complete stubble retention (RET) in eight instances. BURN was significantly lower than RET in only two instances (i.e., the 1996 Kulumsa mechanised and the 1993 Asasa mechanised trials), and was never significantly lower than PARM.

Several reports indicate an immediate yield advantage due to stubble burning, but others indicate inconsistent effects of burning on cereal grain yield (Rasmussen & Rohde, 1988). In the current study, the reduction in yields, due to straw retention in the mentioned years, reflects the effect of wet weather conditions particularly early in the season.

#### **3.2.1.2 Tillage effect**

Response of crop grain yield to tillage varied slightly across years, perhaps in response to the prevailing weather conditions in specific growing seasons. Tillage significantly affected mean grain yield in the mechanised trial at Kulumsa during 1994, 1995 (in wheat only), 1997, 1999 and 2000, in the mechanised trial at Asasa during 1996, 1999 and 2000, in the ox-plow trial at Kulumsa during 1994, 1995 (in both wheat and faba bean) and 2000, and in the ox-plow trial at Asasa during 1994, 1996, 1997 and 2000 (Table 3.2). Except for two trials in 1997 and one trial in 2000, in most instances CT out-yielded ZT in the Kulumsa mechanised trial and MT in the Asasa mechanised trial and at both sites in the

Table 3.1. Straw management effects on grain yield (kg/ha).

Trial	Treatment	1993	1994	1995W	1995Eb	1996	1997	1998W	1998Fb	1999	2000	Mean <sup>a</sup>
Kulumsa Mechanised	Burn	2137	1095A	4787	1686	5544B	4296AB	3229	2969	3932	3846A	3608
	Removal	2243	836B	4954	1796	5603AB	4544A	3019	2963	4013	2748B	3495
	Retention	2230	996B	5169	1914	5864A	4090B	2846	2452	3498	2295B	3374
	Prob.	NS	*	NS	NS	†	*	NS	NS	NS	*	
Kulumsa Ox-plow	Burn	2421	1294	5331A	2126	5545	4823	3089	3218A	4066	4343A	3864
	Removal	2328	1141	4535B	2138	5881	4747	2849	2917B	3781	3141B	3550
	Prob.	NS	NS	*	NS	NS	NS	NS	†	NS	*	
Asasa Mechanised	Burn	1384B	1593	2649A	1398A	4262A	3340	2776A	2958	4294A	3164A	2933
	Removal	1449AB	1573	1615B	848B	3979AB	3195	2410B	3219	3892B	2368B	2560
	Retention	1672A	1559	2689A	949B	3554B	3163	2686A	3051	3964AB	2243B	2691
	Prob.	†	NS	†	*	*	NS	*	NS	†	*	
Asasa Ox-plow	Burn	1713	2093A	3487	1960	4079A	3174	3444	3298	4267A	3358A	3202
	Removal	1816	1726B	2423	1021	3553B	3134	2878	3574	3477B	2313B	2665
	Prob.	NS	†	NS	NS	*	NS	NS	NS	*	*	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup>Mean = wheat mean.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 3.2. Tillage effects on grain yield (kg/ha).

Trial	Treatment	1993	1994	1995W	1995Eb	1996	1997	1998W	1998Eb	1999	2000	Mean <sup>a</sup>
Kulumsa mechanised	CT	2201	1080A	5340A	1870	5617	3987B	3161	3023	4068A	3361A	3602
	ZT	2206	938B	4599B	1727	5724	4630A	2901	2574	3561B	2565B	3390
	Prob.	NS	**	*	NS	NS	*	NS	NS	**	**	
Kulumsa ox-plow	CT	2354	1281A	5259A	2350A	5656	4790	3087	2803	3839	4033A	3787
	MT	2395	1154B	4607B	1914B	5769	4780	2852	3331	4007	3452B	3627
	Prob.	NS	†	**	**	NS	NS	NS	NS	NS	*	
Asasa mechanised	CT	1534	1595	2141	1052	4070A	3287	2611	3094	4314A	3316A	2859
	MT	1471	1555	2494	1078	3793B	3179	2636	3051	3786B	2000B	2614
	Prob.	NS	NS	NS	NS	†	NS	NS	NS	**	***	
Asasa ox-plow	CT	1911	2006A	3334	1628	3963A	2998B	3240	3177	3896	2682B	3004
	MT	1619	1813B	2575	1353	3668B	3310A	3081	3696	3848	2989A	2863
	Prob.	NS	*	NS	NS	†	†	NS	NS	NS	†	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup>Mean = wheat mean.

CT = Conventional tillage; MT = Minimum tillage; ZT = Zero tillage.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

ox-plow trials (Table 3.2). Thus, in the current study, tillage effect on grain yield was more consistent across years than was the case for the effect of stubble management.

Although MT has been stated to be a viable option for wheat production elsewhere in East Africa (Modestus, 1994), in the current study, a biological yield advantage was obtained from ZT/MT only in 1997 in the Kulumsa mechanised trial and in 1997 and 2000 in the Asasa ox-plow trial. Other reports indicate that MT can reduce wheat grain yield in specific environments (Kamwaga, 1990; Kirkegaard *et al.*, 1994). It is important to recall that conservation tillage has been proposed as an alternative to conventional tillage where soil is prone to erosion (Aulakh & Gill, 1988; Stobbe, 1990), and to reduce evaporative losses and enhance soil water in drier environments (Griffith *et al.*, 1986).

### 3.2.1.3 Cropping sequence effect

Cropping sequence (CS) significantly affected wheat grain yield in the Kulumsa mechanised trial during 1993, 1994, 1996, 1997, 1999 and 2000, in the Asasa mechanised trial during 1994, 1996, 1999 and 2000, in the Kulumsa ox-plow trial during 1994, 1996 and 2000, and in the Asasa ox-plow trial during 1993, 1996, 1999 and 2000 (Table 3.3). In each of the 17 instances of CS effect on wheat grain yield, faba bean-wheat (FB-W) or faba bean-wheat-wheat (FB-W-W) treatments were superior to continuous wheat (CW). The effect of CS was non-significant in only seven of the 24 trial-season combinations in which the CS effect on wheat grain yield could be measured (Table 3.3). Interestingly, three instances of non-significance were recorded in the first crop of wheat following faba bean (FB-W) while four instances of non-significance were recorded in the second consecutive wheat crop (FB-W-W).

Thus, dicot crops, especially legumes, should be recommended to be included in the wheat-based cropping systems of Ethiopia. Some authors emphasise the use of crop rotation to sustain wheat production (Higgs *et al.*, 1990; Baldock *et al.*, 1981). Cereals following leguminous crops benefit from lower uptake of soil N by the preceding legume and the carryover of N from the legume crop residues (Danso & Papastylianou, 1992). In one previous study in south-eastern Ethiopia, a significant yield decrease was observed for continuous wheat as relative to wheat following faba bean despite a higher N application

Table 3.3. Cropping sequence effects on grain yield (kg/ha)

Trial	Treatment	1993	1994	1996	1997	1999	2000	Mean
Kulumsa mechanised	Faba bean	2470A	1101A	6201A	4500A	4055A	3239A	3599
	Wheat	2003B	964B	5139B	4118B	3573B	2687B	3081
	Prob.	***	**	***	**	**	***	
Kulumsa ox-plow	Faba bean	2424	1391A	5982A	4845	4142	3985A	3795
	Wheat	2478	1134B	5442B	4725	3705	3499B	3498
	Prob.	NS	†	**	NS	NS	**	
Asasa mechanised	Faba bean	1438	1764A	4532A	3210	4861A	2917A	3120
	Wheat	1417	1405B	3332B	3256	3239B	2399B	2508
	Prob.	NS	***	***	NS	***	**	
Asasa ox-plow	Faba bean	1779A	2035	4278A	3287	4553A	3208A	3190
	Wheat	1545B	1920	3354B	3021	3191B	2463B	2583
	Prob.	***	NS	***	NS	***	***	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

FB = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

to the CW crop. Hailu *et al.* (1989) reported that wheat in continuous monoculture gave 80% lower grain yields than wheat in rotation with faba bean.

### 3.2.2 Biomass yield

#### 3.2.2.1 Straw management effect

Biomass yield (BY) was significantly affected by SM treatments in a relatively consistent manner across locations for both the ox-plow and mechanised systems. A significant effect of SM on BY was observed in the Kulumsa mechanised trial during 1994, 1998 (in faba bean only) and 2000, in the Asasa mechanised trial during 1995 (in wheat only), 1996 and 2000, in the Kulumsa ox-plow trial during 1998 (in both wheat and faba bean) and 2000, and in the Asasa ox-plow trial during 1994, 1995 (in both wheat and faba bean), 1996, 1999 and 2000 (Table 3.4). For the ox-plow trials, BURN resulted in higher BY in nine instances; BURN was never inferior to PARM. In the mechanised trials, BURN was superior to one or both of the other SM treatments in five instances; BURN was intermediate and equal to PARM and RET only in the faba bean crop during 1998 in the Kulumsa mechanised trial. Thus, SM reflected a relatively consistent effect on BY at both sites. Burning of stubble resulted in higher biomass yields in most of the site-season combinations. It is possible that phenomena related to stubble retention, such as nutrient immobilisation, release of toxins, or biological activity restricting root growth, may be involved in the poor performance of the PARM and RET treatments (Heenan *et al.*, 1994).

#### 3.2.2.2 Tillage effect

Wheat BY was significantly affected by tillage treatment in the Kulumsa mechanised trial during 1994, 1995 (in wheat only), 1997, 1999 and 2000, in the Asasa mechanised trial during 1995 (in wheat only), 1996, 1999, and 2000, in the Kulumsa ox-plow trial during 1994, 1995 (in both wheat and faba bean) and 2000, and in the Asasa ox-plow trial during 1994, 1997 and 2000 (Table 3.5). With the exception of 1997 in the Kulumsa mechanised trial, 1995 for wheat in the Asasa mechanised trial, and 1997 and 2000 in the Asasa ox-plow trial, crop BY was significantly higher for the CT treatment in each trial in which a significant effect of tillage was observed. Thus, tillage exhibited a relatively consistent effect on crop BY across locations and years.

Table 3.4. Straw management effects on biomass yield (kg/ha)

Trial	Treatment	1993	1994	1995W	1995Fb	1996	1997	1998W	1998Fb	1999	2000	Mean <sup>a</sup>
Kulumsa mechanised	Burn	6746	4624A	10621	4995	12309	10198	9506	6759AB	8775	9338A	9015
	Removal	7048	4065B	10089	5365	12609	10401	8135	8286A	9192	6917B	8557
	Retention	7256	4227B	10942	4956	12892	9922	8896	5171B	8837	5947B	8615
	Prob.	NS	**	NS	NS	NS	NS	NS	†	NS	*	
Kulumsa ox-plow	Burn	7626	4778	10537	5417	12042	11429	8532A	7632A	8781	10730A	9307
	Removal	7567	4451	10172	4825	12747	11490	7580B	5719B	8450	7506B	8745
	Prob.	NS	NS	NS	NS	NS	NS	†	*	NS	**	
Asasa mechanised	Burn	5009	6042	6644A	3861	10133A	8770	7329	7170	9831	8412A	7771
	Removal	5687	6245	4082B	1751	9094AB	8538	6323	7007	9050	6209B	6904
	Retention	6056	5728	6673A	2593	8367B	8705	7149	6446	9146	6365B	7274
	Prob.	NS	NS	†	NS	†	NS	NS	NS	NS	***	
Asasa ox-plow	Burn	6498	7229A	8834A	4047A	9873A	8682	9465	6294	10032A	8821A	8679
	Removal	6642	5643B	5620B	1929B	8223B	8450	7303	7218	8277B	5787B	6993
	Prob.	NS	†	†	†	†	NS	NS	NS	*	†	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup> Mean = wheat mean.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 3.5. Tillage effects on biomass yield (kg/ha)

Trial	Treatment	1993	1994	1995W	1995Fb	1996	1997	1998W	1998Fb	1999	2000	Mean <sup>a</sup>
Kulumsa mechanised	CT	6865	4582A	11388A	4858	12719	9297B	8637	6362	9447A	8617A	8944
	ZT	7170	4028B	9712B	5352	12488	11050A	9056	7115	8556B	6185B	8531
	Prob.	NS	†	**	NS	NS	*	NS	NS	†	**	
Kulumsa ox-plow	CT	7649	4965A	11266A	5693A	12411	11731	7918	5845	8463	9936A	9292
	MT	7545	4264B	9444B	4825B	12378	11189	8194	7506	8768	8299B	9760
	Prob.	NS	†	†	*	NS	NS	NS	NS	NS	**	
Asasa mechanised	CT	5994	6131	5641B	3060	9558A	8753	6934	6865	10086A	8888A	7748
	MT	5174	5879	5958A	2409	8838B	8589	6933	6884	8599B	5102B	6884
	Prob.	NS	NS	†	NS	†	NS	NS	NS	*	***	
Asasa ox-plow	CT	6708	6801A	8107	3148	9418	8176B	9057	6405	9205	6763B	8029
	MT	6431	6072B	6346	2828	8679	8956A	7710	7107	9103	7845A	7643
	Prob.	NS	*	NS	NS	NS	*	NS	NS	NS	†	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup>Mean = wheat mean.

CT = Conventional tillage; MT = Minimum tillage; ZT = Zero tillage.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

### **3.2.2.3 Cropping sequence effect**

The BY of wheat was significantly affected by CS in the Kulumsa mechanised trial during 1993, 1994, 1996, 1997, 1999 and 2000, in the Asasa mechanised trial during 1994, 1996, 1999 and 2000, in the Kulumsa ox-plow system trial during 1993, 1994, 1996 and 2000, and in the Asasa ox-plow trial during 1993, 1996, 1999 and 2000 (Table 3.6). Across the trials and years, the faba bean rotation significantly and consistently increased the BY of wheat relative to CW. The inclusion of a legume in a cereal-based cropping system contributes additional N fertiliser to enhance the vegetative growth of wheat.

### **3.2.3 Harvest index**

#### **3.2.3.1 Straw management effect**

SM significantly affected harvest index (HI) in the Kulumsa mechanised trial during 1998 and in the ox-plow trials at Kulumsa and Asasa in 2000 (Appendices 3.1, 3.3 and 3.4). In the Kulumsa mechanised trial, PARM significantly increased the HI of wheat relative to RET, but the BURN treatment was intermediate and equal to both of the other treatments. In the case of the ox-plow trials at Kulumsa and Asasa, PARM significantly increased the HI of the wheat crop relative to the BURN treatment. However, for most site-season combinations, there was no significant effect of SM treatment on HI (Appendices 3.1 to 3.4).

#### **3.2.3.2 Tillage effect**

Tillage treatment significantly affected the HI of wheat only in the mechanised trial at Kulumsa during 1996 and 2000, and in the mechanised trial at Asasa during 2000 (Appendices 3.1 and 3.2). In each case, ZT/MT significantly increased HI relative to CT (Appendices 3.1 and 3.2). Overall, tillage treatment showed little effect on the HI of wheat (Appendices 3.1 to 3.4).

Table 3.6. Cropping sequence effects on biomass yield (kg/ha).

Trial	Treatment	1993	1994	1996	1997	1999	2000	Mean
Kulumsa mechanised	Faba bean	8542A	4789A	13392A	10586A	9609A	8164A	9180
	Wheat	6048B	4180B	11815B	9762B	8393B	6638B	7806
	Prob.	***	*	**	*	†	***	
Kulumsa ox-plo w	Faba bean	8081A	7518A	13051A	11588	8956	9692A	9514
	Wheat	7791B	4198B	11783B	11332	8275	8544B	8646
	Prob.	†	**	**	NS	NS	*	
Asasa mechanised	Faba bean	5616	6513A	10389A	8790	11227A	7644A	8363
	Wheat	5197	5614B	8007B	8552	7456B	6341B	6862
	Prob.	NS	†	***	NS	***	**	
Asasa ox-plo w	Faba bean	7290A	6630	10234A	8912	10718A	8526A	8719
	Wheat	5733B	6664	7862B	8220	7590B	6082B	7025
	Prob.	*	NS	***	NS	***	***	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

FB = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

### 3.2.3.3 Cropping sequence effect

CS significantly increased the HI of wheat in the Kulumsa mechanised trial during 1993 and 1996, and in the Asasa mechanised trial during 1996 and 1997 (Appendices 3.1 and 3.2). During 1993 in the Kulumsa mechanised trial and during 1997 in the Asasa mechanised trial, the CW treatment exhibited a markedly increased HI of wheat, but, in the mechanised trials at Kulumsa and Asasa during 1996, the faba bean rotation significantly increased the HI of wheat. Thus, CS exhibited a minimal and inconsistent effect on the HI of wheat across locations and seasons.

## 3.2.4 Spikes/m<sup>2</sup>

### 3.2.4.1 Straw management effect

Spikes/m<sup>2</sup> (SPM) was significantly affected by SM in the Kulumsa mechanised trial during 1997, in the Asasa mechanised trial during 1995 (in wheat only), 1996, 1998 (in wheat only) and 1999, in the Kulumsa ox-plow trial during 1996, 1998 (in faba bean only), 1999 and 2000, and in the Asasa ox-plow trial during 1997 and 2000 (Table 3.7). In most instances of significance, SPM was higher for the BURN treatment than for the alternative(s). In the Kulumsa mechanised trial, RET of crop stubble resulted in the lowest SPM in 1997. In the Asasa mechanised trial, BURN increased SPM relative to the PARM and RET treatments, except during 1996 when RET < BURN and PARM was intermediate and equal to the other two treatments (Table 3.7). In the Kulumsa ox-plow trial, BURN < PARM during 1996 and 1999, while BURN > PARM during 1999 and 2000 (Table 3.7). In the Asasa ox-plow trial, the BURN treatment significantly increased SPM during 1997 and 2000. Thus, SM treatments exhibited an inconsistent effect on wheat SPM across seasons and sites.

### 3.2.4.2 Tillage effect

SPM was significantly affected by the tillage treatments in the Kulumsa mechanised trial during 1995 (in both wheat and faba bean), in the Asasa mechanised trial during 1993, 1996, 1997, 1999 and 2000, in the Kulumsa ox-plow trial during 1998 (in wheat only) and 1999, and in the Asasa ox-plow trial during 1995 (in faba bean only) (Table 3.8). Thus, for

most site-season combinations, the effect of tillage on SPM was non-significant. In the Kulumsa mechanised trial, ZT significantly increased the SPM of wheat, while CT increased the SPM of faba bean (Table 3.8). In the Asasa mechanised trial, CT consistently increased the SPM of wheat in those site-season combinations exhibiting significance. In the Kulumsa ox-plow trial, a significant increase was exhibited under CT during 1998, but, during 1999, the opposite was true, reflecting an inconsistent effect of tillage on the SPM of wheat. In the Asasa ox-plow trial, SPM was only affected by tillage during 1995, when CT significantly increased SPM (Table 3.8).

### 3.2.4.3 Cropping sequence effect

The SPM of wheat was significantly affected by CS in the Kulumsa mechanised trial during 1993, 1996 and 1997, in the Asasa mechanised trial during 1993, 1996 and 1999, in the Kulumsa ox-plow trial during 1994, and in the Asasa ox-plow trial during 1996, 1997, 1999 and 2000 (Table 3.9). In each instance of significance, FB-W or FB-W-W significantly increased the SPM of wheat relative to CW. This result indicates that including legumes in the cropping sequence provides multiple benefits. Crop rotation with legumes fixes nitrogen and enhances dietary protein, and provides ground cover to reduce soil erosion (Dordio, 1990; Bohlool *et al.*, 1992). Danso & Papastylianou (1992) also suggested that the N benefit to cereal crops grown after grain legumes was due to a lower uptake of soil N by legumes relative to cereals and a carryover of N from the legume residue. Both factors resulted in a greater uptake of soil N by subsequent crops, thereby increasing yield and yield components. Asefa *et al.* (1992) reported a marked improvement in some yield components of wheat, such as spikes m<sup>-2</sup>, following a legume precursor crop.

## 3.2.5 Thousand kernel weight

### 3.2.5.1 Straw management effect

Thousand kernel weight (TKW) was significantly affected by SM in the Kulumsa mechanised trial during 1996, 1998 (in wheat only) and 1999, in the Asasa mechanised trial during 1993 and 1999, and in the Kulumsa ox-plow trial during 1994, 1995 (in faba bean only), 1996 and 1998 (in wheat only). In the Asasa ox-plow trial, SM had no effect on TKW (Table 3.10). The SM effects were not consistent, but the BURN treatment tended to result in the lowest TKW. In the Kulumsa mechanised trial, RET markedly

Table 3.7. Straw management effects on spikes/m<sup>2</sup>

Trial	Treatment	1993	1994	1995W	1995Fb	1996	1997	1998W	1998Fb	1999	2000	Mean <sup>a</sup>
Kulumsa mechanised	Burn	455	453	542	80.3	446	498AB	397	19.0	496	538	478
	Removal	475	462	556	75.0	455	535A	355	19.2	491	497	478
	Retention	475	462	566	68.5	442	438B	386	14.5	489	459	465
	Prob.	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	
Kulumsa ox-plow	Burn	447	338	373	63.8	346B	337	388	29.5B	353A	426A	376
	Removal	435	340	422	67.2	372A	374	343	33.8A	309B	358B	369
	Prob.	NS	NS	NS	NS	*	NS	NS	*	*	*	
Asasa mechanised	Burn	423	442	341A	42.3	461A	444	467A	35.8	489A	296	420
	Removal	438	465	190C	42.2	406AB	451	395B	35.3	438B	278	383
	Retention	448	466	257B	42.7	351B	408	343B	33.8	423B	297	374
	Prob.	NS	NS	**	NS	*	NS	*	NS	*	NS	
Asasa ox-plow	Burn	450	411	352	38.8	426	463A	426	38.0	471	373A	422
	Removal	470	404	226	33.0	372	427B	419	40.0	431	296B	381
	Prob.	NS	NS	NS	NS	NS	†	NS	NS	NS	*	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup> Mean = wheat mean.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 3.8. Tillage effects on spikes/m<sup>2</sup>.

Trial	Treatment	1993	1994	1995W	1995Fb	1996	1997	1998W	1998Fb	1999	2000	Mean <sup>a</sup>
Kulumsa mechanised	CT	480	447	527B	79.7A	442	502	390	18.2	496	512	475
	ZT	457	442	582A	69.4B	454	479	369	16.8	489	480	469
	Prob.	NS	NS	†	*	NS	NS	NS	NS	NS	NS	
Kulumsa ox-plow	CT	441	344	384	62.5	363	397	402A	33.2	312B	396	380
	MT	441	333	410	68.5	353	372	329B	30.2	350A	388	372
	Prob.	NS	NS	NS	NS	NS	NS	**	NS	†	NS	
Asasa mechanised	CT	451A	466	279	44.1	432A	449A	420	34.9	465A	336A	412
	MT	422B	450	246	40.7	380B	419B	384	35.1	435B	244B	373
	Prob.	†	NS	NS	NS	†	*	NS	NS	**	**	
Asasa ox-plow	CT	457	409	305	40.5A	409	438	429	38.0	460	327	404
	MT	464	405	274	31.3B	389	453	417	39.8	442	342	398
	Prob.	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup>Mean = wheat mean.

CT = Conventional tillage; MT = Minimum tillage; ZT = Zero tillage.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 3.9. Cropping sequence effects on spikes/m<sup>2</sup>

Trial	Treatment	1993	1994	1996	1997	1999	2000	Mean
Kulumsa mechanised	Faba bean	501A	459	472A	509A	489	494	487
	Wheat	415B	465	424B	472B	495	499	461
	Prob.	†	NS	**	†	NS	NS	
Kulumsa ox-plow	Faba bean	459	378A	364	372	336	374	381
	Wheat	434	316B	353	380	326	410	370
	Prob.	NS	*	NS	NS	NS	NS	
Asasa mechanised	Faba bean	448A	475	439A	437	497A	301	433
	Wheat	420B	461	372B	437	403B	279	394
	Prob.	†	NS	**	NS	***	NS	
Asasa ox-plow	Faba bean	444	416	419A	451A	478A	364A	429
	Wheat	487	396	379B	439B	424B	304B	405
	Prob.	NS	NS	*	*	**	*	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

FB = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

increased TKW cf. BURN, while PARM was intermediate and equal to the other two treatments during 1996. During 1998 and 1999, PARM significantly increased TKW relative to the RET treatment, while the BURN treatment was intermediate and equal to RET and PARM. In the mechanised trial at Asasa, RET significantly increased TKW cf. BURN in 1993. However, during 1999, TKW followed the order of ranking RET > PARM > BURN. In the ox-plow trial at Kulumsa, BURN and PARM significantly increased TKW in specific seasons, reflecting an inconsistent pattern (Table 3.10).

### **3.2.5.2 Tillage effect**

TKW was significantly affected by tillage in the Kulumsa mechanised trial during 1999 and 2000, in the Asasa mechanised trial during 1995 (in wheat only), 1996, 1998 (in wheat only) and 2000, in the Kulumsa ox-plow trial during 1996, 1997 and 1998 (in wheat only), and in the Asasa ox-plow trial during 1997 and 1998 (in faba bean only) (Table 3.11). In all instances of significance, ZT/MT increased TKW cf. the CT treatment, reflecting a consistent effect on TKW across all sites and seasons. Ciha (1982) reported a heavier 1000 grain weight for spring wheat grown under reduced tillage cf. conventional tillage.

### **3.2.5.3 Cropping sequence effect**

CS significantly affected TKW in the Kulumsa mechanised trial during 1996 and 2000, in the Asasa mechanised trial during 1993, 1994 and 1996, in the Kulumsa ox-plow trial during 1993 and 1996, and in the Asasa ox-plow trial during 1996 and 2000 (Table 3.12). The faba bean rotation significantly increased wheat TKW in five trials while TKW was markedly increased in four trials by the CW treatment, reflecting an inconsistent pattern. The reduction of TKW in the FB rotation probably reflected the higher demands for water and nutrients during vegetative growth and grain filling under higher biomass conditions. In a previous report, wheat following a grain legume exhibited a greater number of spikes  $m^{-2}$  and an increase in test weight (Badaruddin & Meyer, 1994).

Table 3.10. Straw management effects on thousand kernel weight (g)

Trial	Treatment	1993	1994	1995W	1995Fb	1996	1997	1998W	1998Fb	1999	2000	Mean <sup>a</sup>
Kulumsa mechanised	Burn	23.6	19.4	33.9	435	34.0B	31.9	22.2AB	450	33.4AB	29.4	28.5
	Removal	24.3	19.3	34.5	445	36.0AB	32.9	24.6A	377	34.2A	31.6	29.7
	Retention	23.5	19.5	36.2	457	37.0A	32.7	20.6B	424	32.5B	29.2	28.9
	Prob.	NS	NS	NS	NS	†	NS	†	NS	*	NS	
Kulumsa ox-plow	Burn	23.8	22.5A	36.7	432B	34.8B	33.1	19.5B	442	34.1	31.7	29.5
	Removal	23.4	21.4B	36.6	450A	36.6A	33.9	23.9A	448	34.8	32.7	30.4
	Prob.	NS	*	NS	†	†	NS	**	NS	NS	NS	
Asasa mechanised	Burn	18.5B	20.4	31.4	479	32.4	28.8	28.3	490	33.1C	30.5	27.9
	Removal	19.2AB	20.7	29.4	457	33.2	30.2	30.8	448	34.0B	31.4	28.6
	Retention	19.9A	20.8	31.1	462	32.6	29.2	29.5	524	35.2A	31.5	28.7
	Prob.	*	NS	NS	NS	NS	NS	NS	NS	**	NS	
Asasa ox-plow	Burn	18.7	22.6	34.8	695	34.1	28.2	28.6	516	33.5	31.5	29.0
	Removal	18.7	22.2	37.7	656	33.1	27.6	27.6	524	32.3	31.2	28.8
	Prob.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup>Mean = wheat mean.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

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Table 3.11. Tillage effects on thousand kernel weight (g).

Trial	Treatment	1993	1994	1995W	1995Eb	1996	1997	1998W	1998Eb	1999	2000	Mean <sup>a</sup>
Kulumsa mechanised	CT	24.1	19.0	36.6	456	34.7	32.1	21.9	410	32.4B	28.8B	28.7
	ZT	23.5	18.0	34.1	438	35.6	32.8	23.0	424	34.8A	31.3A	29.1
	Prob.	NS	NS	NS	NS	NS	NS	NS	NS	*	**	
Kulumsa ox-plow	CT	23.5	22.3	36.9	444	35.0B	32.7B	21.1B	458	34.2	32.1	29.7
	MT	23.7	21.6	36.4	439	36.4A	34.3A	22.1A	433	34.7	32.3	30.2
	Prob.	NS	NS	NS	NS	***	**	*	NS	NS	NS	
Asasa mechanised	CT	18.7	20.6	30.1B	466	31.8B	29.0	29.0B	448	34.1	30.4B	28.0
	MT	19.7	20.6	31.3A	466	33.6A	29.9	30.3A	529	34.2	31.8A	28.9
	Prob.	NS	NS	*	NS	*	NS	*	NS	NS	*	
Asasa ox-plow	CT	19.2	22.6	36.6	706	33.1	26.7B	27.5	487B	32.7	31.3	28.7
	MT	18.2	22.3	36.0	644	34.1	29.1A	28.6	553A	32.1	31.4	29.0
	Prob.	NS	NS	NS	NS	NS	**	NS	*	NS	NS	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup> Mean = wheat mean.

CT = Conventional tillage; MT = Minimum tillage; ZT = Zero tillage.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 3.12. Cropping sequence effects on thousand kernel weight (g)

Trial	Treatment	1993	1994	1996	1997	1999	2000	Mean
Kulumsa mechanised	Faba bean	23.3	20.0	35.7A	32.7	33.6	29.3B	29.0
	Wheat	24.1	19.0	34.5B	32.3	33.1	30.8A	29.0
	Prob.	NS	NS	*	NS	NS	*	
Kulumsa ox-plow	Faba bean	21.2B	21.9	36.2A	33.6	34.3	31.7	29.8
	Wheat	24.6A	22.3	35.2B	33.4	34.6	32.7	30.5
	Prob.	***	NS	†	NS	NS	NS	
Asasa mechanised	Faba bean	18.2B	20.8A	34.2A	27.3	34.4	30.7	27.9
	Wheat	19.5A	20.0B	31.4B	31.0	33.9	31.5	27.6
	Prob.	*	**	**	NS	NS	NS	
Asasa ox-plow	Faba bean	17.6	22.5	34.2A	28.2	32.7	30.7B	27.6
	Wheat	18.1	22.8	32.9B	27.6	32.1	32.0A	27.6
	Prob.	NS	NS	*	NS	NS	**	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

FB = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability)

### **3.2.6 Grains/spike**

#### **3.2.6.1 Straw management effect**

SM significantly influenced grains/spike (GPS) in the Kulumsa mechanised trial during 2000, in the Asasa mechanised trial during 1994, 1998 and 2000, and in the Kulumsa ox-plow trial during 2000 (Appendices 3.1, 3.2 and 3.3). In the Kulumsa mechanised trial, the BURN treatment significantly increased GPS cf. the other two treatments. In the Asasa mechanised trial, during 1998, RET resulted in the highest GPS, while during 1994 and 2000, the BURN treatment significantly increased SPM. The Asasa ox-plow trial did not exhibit a significant effect of SM treatments on GPS in any year (Appendix 3.4).

#### **3.2.6.2 Tillage effect**

Tillage treatment significantly affected GPS in the Kulumsa mechanised trial during 1995, 1997, 1999 and 2000, and in the Asasa mechanised trial only during 1995. In the Kulumsa mechanised trial during 1997 and the Asasa mechanised trial during 1995, ZT/MT resulted in a higher GPS than CT. By contrast, in the mechanised trial at Kulumsa during 1995, 1999 and 2000, CT significantly increased GPS. The ox-plow trials at Asasa and Kulumsa did not exhibit a significant effect of tillage on GPS in any year (Appendices 3.3 and 3.4).

#### **3.2.6.3 Cropping sequence effect**

GPS was significantly affected by CS in the Kulumsa mechanised trial during 1993, 1999 and 2000, in the Asasa mechanised trial during 1999 and 2000, in the Kulumsa ox-plow trial during 2000, and in the Asasa ox-plow trial during 1993, 1999 and 2000 (Appendices 3.1 to 3.4). In each instance of significance, FB-W or FB-W-W exhibited a significantly increased GPS relative to CW.

### **3.2.7 Wheat seedling biomass**

#### **3.2.7.1 Straw management effect**

Wheat seedling biomass (WSB) was significantly affected by SM treatments in the Kulumsa mechanised trial during 2000, in the Asasa mechanised trial during 1995, 1996 and 2000, in the Kulumsa ox-plow trial during 1996 and 1997, and in the Asasa ox-plow

trial during 1996 and 2000 (Table 3.13). In the mechanised trials, the BURN treatment exhibited a significantly higher WSB than both of the other SM treatments in two instances. In two other instances, the BURN treatment was greater than PARM. In the ox-plow trials, the BURN treatment markedly increased WSB relative to PARM in each of the four instances of significance (Table 3.13). Thus, SM treatments reflected a consistent effect on WSB in the ox-plow trials across locations and seasons.

**Table 3.13. Straw management effect on wheat seedling biomass (kg/ha)**

Trial	Treatment	1995	1996	1997	1998	1999	2000	Mean <sup>a</sup>
Kulumsa mechanised	Burn	278	1422	2094	1306	903	3700A	1617
	Removal	231	1317	1943	1080	847	2797B	1369
	Retention	276	1255	2153	1158	867	2726B	1406
	Prob.	NS	NS	NS	NS	NS	*	
Kulumsa ox-plow	Burn	300	1526A	1966A	1981	944	1282	1333
	Removal	269	1367B	1698B	1874	906	1266	1230
	Prob.	NS	*	*	NS	NS	NS	
Asasa mechanised	Burn	735A	1523A	1402	1472	1569	2940A	1607
	Removal	572B	1028C	1392	1406	1220	2530B	1358
	Retention	672AB	1196B	1352	1309	1370	2972A	1479
	Prob.	†	†	NS	NS	NS	*	
Kulumsa ox-plow	Burn	321	1708A	1733	2265	1396	1016A	1407
	Removal	281	1397B	1609	1901	1317	848B	1159
	Prob.	NS	†	NS	NS	NS	*	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup> Mean = wheat mean.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

### 3.2.7.2 Tillage effect

Tillage significantly affected WSB in the Kulumsa mechanised trial during 1998, in the Asasa mechanised trial during 1995, 1999 and 2000, in the Kulumsa ox-plow trial during 1996 and 1997, and in the Asasa ox-plow trial during 1996 and 1999 (Table 3.14). With the exception of the Asasa mechanised trial during 1995 and the Kulumsa ox-plow trial during 1996, CT significantly increased WSB for each instance of significance (Table 3.14). In another report, reductions in seedling biomass with direct drilling were related to reduced growth per shoot rather than reduced plant density or tillering (Kirkegaard *et al.*, 1994). Cornish & Lymbery (1987) reported that reduced shoot growth on direct drilled soil was related to reduced root growth in a high strength soil. A possible explanation was

provided by Malse & Passioura (1987) who demonstrated that shoot growth of wheat seedlings in high strength soil could be reduced independently of water or P-supply.

**Table 3.14. Tillage effects on wheat seedling biomass (kg/ha).**

Trial	Treatment	1995	1996	1997	1998	1999	2000	Mean
Kulumsa mechanised	CT	269	1344	2011	1385A	867	3195	1512
	ZT	254	1319	2110	978B	880	2960	1367
	Prob.	NS	NS	NS	*	NS	NS	
Kulumsa ox-plow	CT	292	1283B	1968A	1863	899	1307	1264
	MT	277	1611A	1698B	1993	952	1241	1295
	Prob.	NS	*	†	NS	NS	NS	
Asasa mechanised	CT	610B	1239	1359	1386	1560A	4037A	1699
	MT	721A	1168	1402	1405	1211B	1593B	1250
	Prob.	*	NS	NS	NS	*	***	
Asasa ox-plow	CT	313	1776A	1698	2201	1568A	943	1417
	MT	289	1329B	1644	2329	1145B	921	1276
	Prob.	NS	*	NS	NS	*	NS	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

<sup>a</sup> Mean = wheat mean.

CT = Conventional tillage; MT = Minimum tillage; ZT = Zero tillage.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

### 3.2.7.3 Cropping sequence effect

CS significantly affected WSB in the Kulumsa mechanised trial during 1996 and 2000, in the Asasa mechanised trial during 1999, in the Kulumsa ox-plow trial during 2000, and in the Asasa ox-plow trial during 1996 and 1999. In each instance of significance, FB-W or FB-W-W exhibited a significantly higher WSB cf. CW (Table 3.15).

## 3.3 Combined analysis

The results of the combined ANOVA across years for yield and yield components in the mechanised and ox-plow trials at Kulumsa and Asasa are presented in Tables 3.16 to 3.20. The results for wheat grain yield and biomass yield (Tables 3.16 and 3.17) revealed that year, SM by year, tillage by year, CS, and CS by year effects comprised a high proportion of the total variability, reflecting pronounced environmental effects on the grain yield and biomass yield of wheat. By comparison, there were fewer significant effects apparent in the ANOVA results for SPM, TKW, and WSB (Tables 3.18 to 3.20).

Table 3.15. Cropping sequence effects on wheat seedling biomass (kg/ha).

Trial	Treatment	1996	1997	1999	2000	Mean
Kulumsa mechanised	FB	1426A	2136	903	3448A	2431
	W	1237B	1996	840	2706B	2116
	Prob.	*	NS	NS	†	
Kulumsa ox-plow	FB	1541	1849	933	1373A	1424
	W	1352	1817	918	1174B	1315
	Prob.	NS	NS	NS	†	
Asasa mechanised	FB	1290	1366	1552A	2916	1781
	W	1208	1400	1221B	2714	1636
	Prob.	NS	NS	*	NS	
Asasa ox-plow	FB	1762A	1671	1594A	925	1488
	W	1343B	1671	1119B	939	1268
	Prob.	*	NS	**	NS	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

FB = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 3.16. Crop management effects on wheat grain yield (kg/ha) in the mechanised and ox-plow system trials at Kulumsa and Asasa: ANOVA results across six years (1993-94, 1996-97, 1999-2000).

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Year (Y)	***	***	***	***
Straw management (SM)				*
SM x Y	**	**	**	*
Tillage (T)		†		
T x Y	***	***	*	*
SM x T				
SM x T x Y		†		
Cropping sequence (CS)	***	†	*	*
CS x Y		***	†	***
SM x CS		*		
SM x CS x Y			***	
T x CS		**		
T x CS x Y			**	
SM x T x CS	†			
SM x T CS x Y				
Mean	3340	2814	3646	2886
C.V.(%)	10.6	13.3	10.8	12.0

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

**Table 3.17. Crop management effects on wheat biomass yield (kg/ha) in the mechanised and ox-plover system trials at Kulumsa and Asasa: ANOVA results across six years (1993-94, 1996-97, 1999-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plover	Asasa ox-plover
Year (Y)	***	***	***	***
Straw management (SM)				*
SM x Y	***	**	**	**
Tillage (T)		†	*	
T x Y	**	***		*
SM x T				
SM x T x Y	**			
Cropping sequence (CS)	***	*	***	*
CS x Y		***		***
SM x CS	*			
SM x CS x Y			*	
T x CS	*	*		
T x CS x Y			*	
SM x T x CS	†			
SM x T CS x Y				
Mean	8493	7612	9080	7871
C.V.(%)	12.8	14.8	13.7	15.3

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

**Table 3.18. Crop management effects on wheat spikes/m<sup>2</sup> in the mechanised and ox-plover system trials at Kulumsa and Asasa: ANOVA results across six years (1993-94, 1996-97, 1999-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plover	Asasa ox-plover
Year (Y)		***	**	**
Straw management (SM)				
SM x Y		**		*
Tillage (T)		*		
T x Y		**		
SM x T				
SM x T x Y				
Cropping sequence (CS)	*	*		
CS x Y		*	*	**
SM x CS				*
SM x CS x Y				
T x CS				
T x CS x Y				
SM x T x CS		**	**	
SM x T CS x Y				
Mean	474	414	375	417
C.V.(%)	18.5	14.8	11.7	11.1

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

**Table 3.19. Crop management effects on thousand kernel weight (g) in the mechanised and ox-plow system trials at Kulumsa and Asasa: ANOVA results across six years (1993-94, 1996-97, 1999-2000).**

	Kulumsa Mechanised	Asasa Mechanised	Kulumsa ox-plow	Asasa ox-plow
Year (Y)	***	***	***	***
Straw management (SM)	*	†		
SM x Y			†	
Tillage (T)		*		*
T x Y	***			
SM x T				
SM x T x Y	†		**	
Cropping sequence (CS)				
CS x Y	**	***	***	*
SM x CS				
SM x CS x Y				
T x CS	*			
T x CS x Y			**	
SM x T x CS		*		*
SM x T CS x Y				
Mean	29.0	27.8	30.2	27.6
C.V.(%)	5.35	6.07	4.39	4.94

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

**Table 3.20. Crop management effects on wheat seedling biomass dry weight (kg/ha) in the mechanised and ox-plow system trials at Kulumsa and Asasa: ANOVA results across four years (1996-97, 1999-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Year (Y)	***	***	*	***
Straw management (SM)		**	*	**
SM x Y	*			
Tillage (T)				
T x Y		***	**	*
SM x T				
SM x T x Y	**			*
Cropping sequence (CS)	**		*	
CS x Y				**
SM x CS				
SM x CS x Y				
T x CS			†	
T x CS x Y				
SM x T x CS				†
SM x T CS x Y				
Mean	2273	1708	1369	1378
C.V.(%)	27.8	36.9	14.8	18.0

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$ , and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

### 3.3.1 Grain yield

SM significantly affected the grain yield of wheat only in the Asasa ox-plow trial (Table 3.21). In this trial, the BURN treatment markedly increased the grain yield of wheat cf. PARM of the stubble. The mechanised trials at Kulumsa and Asasa and the ox-plow trial at Kulumsa did not exhibit a significant effect of SM treatments on grain yield (Table 3.21) because the SM effects were not consistent across years (Table 3.1).

For the same reason, tillage did not reflect a significant effect on wheat grain yield across years for any of the trials (Table 3.21).

By contrast, the effect of CS on grain yield was relatively consistent across years (Table 3.3). Thus, in the combined ANOVA, CS significantly affected the grain yield of wheat in the mechanised and ox-plow trials at Kulumsa and in the ox-plow trial at Asasa (Table 3.21). In each instance, the FB-based rotation significantly increased the grain yield of wheat cf. CW (Table 3.21).

**Table 3.21. Crop management effects on wheat grain yield (kg/ha) in the mechanised and ox-plow system trials at Kulumsa and Asasa: treatment means across six years (1993-94, 1996-97, 1999-2000)**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Straw management				
Burn	3489	2976	3768	3112A
Removal	3367	2730	3525	2661B
Retention	3162	2736	--	--
Tillage				
Conventional	3402	3016	3682	2915
Zero/Minimum	3278	2611	3610	2857
Cropping sequence				
Faba bean	3599A	3120	3795A	3190A
Wheat	3081B	2508	3498B	2583B
Year				
1993	2250E	1427D	2451D	1662E
1994	1032F	1584D	1263E	1978D
1996	5670A	3932A	5713A	3816A
1997	4309B	3233B	4785B	3154B
1999	3815C	4050A	3924C	3872A
2000	2963D	2658C	3742C	2836C
LSD(5%)	291	413	337	266

Values followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.

Year significantly affected the grain yield of wheat in all four trials (Table 3.21). The highest grain yields of wheat in the mechanised and ox-plow trials at Kulumsa were obtained during 1996 (Table 3.21). In the mechanised and ox-plow trials at Asasa, high yields were observed during 1996 and 1999. The lowest wheat grain yields were observed during 1994 at Kulumsa for both system trials. In the mechanised trial at Asasa, the lowest yields were obtained during 1993 and 1994; in the ox-plow trial at Asasa, the lowest yield was recorded during 1993 (Table 3.21).

### 3.3.2 Biomass yield

In the combined ANOVA, SM significantly affected wheat biomass yield only in the ox-plow trial at Asasa (Table 3.22). In this trial, the BURN treatment outyielded the PARM treatment. Despite exhibiting the highest mean yield for the BURN treatment, the mechanised trials at Kulumsa and Asasa and the ox-plow trial at Kulumsa did not exhibit a significant effect of SM treatment on the biomass yield of wheat (Table 3.22) due to inconsistent effects across years (Table 3.4).

Similarly, tillage significantly affected the biomass yield of wheat in the combined ANOVA only in the Kulumsa ox-plow trial (Table 3.22). CT increased the biomass yield of wheat cf. MT. For the other three trials, no significant differences were detected in the biomass yield of wheat due to tillage. However, in each trial, CT appeared to outperform ZT/MT.

CS significantly affected the biomass yield of wheat in the combined ANOVA for each trial (Table 3.22). In all four trials, the FB-based rotation significantly increased the biomass yield of wheat cf. CW (Table 3.22).

Year also significantly affected wheat biomass yield in all four trials (Table 3.22). The highest mean wheat biomass yields were obtained in 1996 in both trials at Kulumsa. At Asasa, the highest mean wheat biomass yields were recorded in 1996, 1997 and 1999 in both trials. Thus, the weather conditions in a given year affected the ox-plow and mechanised trials equally at both sites.

**Table 3.22. Crop management effects on wheat biomass yield (kg/ha) in the mechanised and ox-plow system trials at Kulumsa and Asasa: treatment means across six years (1993-94, 1996-97, 1999-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Straw management				
Burn	8747	7954	9347	8593A
Removal	8508	7465	8814	7149B
Retention	8224	7419	---	---
Tillage				
Conventional	8649	8254	9335A	7936
Zero/Minimum	8337	6971	8826B	7808
Cropping sequence				
Faba bean	9180A	8363A	9514A	8719A
Wheat	7806B	6862B	8646B	7025B
Year				
1993	7295D	5407C	7936D	6512C
1994	4485E	6063BC	4958E	6646C
1996	12605A	9198A	12395A	9048A
1997	10174B	8671A	11460B	8566A
1999	9001C	9342A	8616CD	9154A
2000	7401D	6995B	9118C	7304B
LSD(5%)	951	1108	735	604

Values followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.

### 3.3.3 Spikes/m<sup>2</sup>

SM treatment failed to exhibit a significant effect on wheat SPM in the combined ANOVA for any of the four trials (Table 3.23).

Tillage significantly affected SPM only in the Asasa mechanised trial where, CT significantly increased SPM (Table 3.23).

CS significantly affected SPM in the two mechanised trials (Table 3.23) where the FB-based rotation increased SPM cf. CW.

The year effect significantly affected wheat SPM in the Asasa mechanised trial and the ox-plow trials at both sites (Table 3.23), while the Kulumsa mechanised trial did not exhibit a significant effect of year on SPM.

**Table 3.23. Crop management effects on wheat spikes/m<sup>2</sup> in the mechanised and ox-plow system trials at Kulumsa and Asasa: treatment means across six years (1993-94, 1996-97, 1999-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Straw management				
Burn	480	425	382	432
Removal	482	418	369	402
Retention	461	398	--	--
Tillage				
Conventional	483	434A	375	414
Zero/Minimum	466	394B	375	420
Cropping sequence				
Faba bean	487A	433A	381	429
Wheat	461B	394B	370	405
Year				
1993	458	434B	447A	465A
1994	462	468A	347CD	406B
1996	448	406C	358BCD	399B
1997	491	434B	376BC	445A
1999	492	449AB	331D	451A
2000	496	290D	392B	334C
LSD(5%)	NS	20.6	36.1	38.7

Values followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.

### 3.3.4 Thousand kernel weight

SM significantly affected TKW in the combined ANOVA for the mechanised trials at Kulumsa and Asasa (Table 3.24). In the trial at Kulumsa, BURN < PARM, while RET of crop stubble was intermediate and equal to the other two treatments. At Asasa, BURN < RET while PARM was intermediate and equal to the RET and BURN treatments. Thus, in both trials, the BURN treatment resulted in the lowest TKW of wheat.

Tillage significantly affected TKW in the mechanised and ox-plow trials at Asasa (Table 3.24). In each trial, MT significantly increased the TKW of wheat cf. CT. The same trend was apparent but non-significant in both trials at Kulumsa.

CS did not affect the TKW of wheat in the combined ANOVA for any of the four trials (Table 3.24).

Year significantly affected TKW in all four trials (Table 3.24). The highest TKW was obtained during 1996 in the Kulumsa mechanised and Asasa ox-plow trials. In the

Kulumsa ox-plow trial, the highest TKWs were observed during 1996 and 1999. In the Asasa mechanised trial, the highest TKW was observed during 1999.

**Table 3.24. Crop management effects on thousand kernel weight (g) in the mechanised and ox-plow system trials at Kulumsa and Asasa: treatment means across six years (1993-94, 1996-97, 1999-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Straw management				
Burn	28.6B	27.2B	29.9	27.8
Removal	29.6A	27.9AB	30.4	27.4
Retention	28.9AB	28.2A	--	--
LSD(5%)	0.72	0.86		
Tillage				
Conventional	28.6	27.4B	29.9	27.4B
Zero/Minimum	29.4	28.2A	30.4	27.8A
Cropping sequence				
Faba bean	29.0	27.9	29.8	27.6
Wheat	29.0	27.7	30.5	27.6
Year				
1993	23.7D	18.9F	22.9D	17.8F
1994	19.4E	20.4E	22.2D	22.6E
1996	35.1A	32.7B	35.7A	33.6A
1997	32.5B	29.5D	33.5B	27.9D
1999	33.4B	34.1A	34.5AB	32.4B
2000	30.1C	31.1C	32.2C	31.3C
LSD(5%)	1.24	0.88	1.74	0.80

Values followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.

### 3.3.5 Wheat seedling biomass

SM significantly affected wheat seedling biomass in the Asasa mechanised trial and in the ox-plow trials at both sites (Table 3.25). In the Asasa mechanised trial, WSB followed the ranking BURN > RET > PARM. In the ox-plow trials at both sites, the BURN treatment significantly increased WSB cf. the PARM treatment.

Tillage did not exhibit a significant effect on WSB in any of the four trials (Table 3.25).

CS significantly affected WSB in the mechanised and ox-plow trials at Kulumsa (Table 3.25). In both trials, the FB-based rotation increased WSB cf. the CW treatment.

Year significantly affected WSB in all four trials (Table 3.25). In the mechanised trials at Kulumsa and Asasa, the highest WSB was obtained during 1999, whereas in the ox-plow trials at both sites, the highest WSB was observed during 1996 (Table 3.25).

**Table 3.25. Crop management effects on wheat seedling biomass dry weight (kg/ha) in the mechanised and ox-plow system trials at Kulumsa and Asasa: treatment means across four years (1996-97, 1999-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Straw management				
Burn	2485	1859A	1429A	1463A
Removal	2151	1543C	1309B	1293B
Retention	2185	1733B	--	--
LSD(5%)	NS	15.8		
Tillage				
Conventional	2288	2071	1364	1496
Zero/Minimum	2259	1345	1375	1259
Cropping sequence				
Faba bean	2431A	1781	1424A	1488
Wheat	2116B	1636	1315B	1268
Year				
1996	1331D	1249C	1446B	1553B
1997	2063C	1383B	1833A	1671A
1999	2622B	1387B	925D	1356C
2000	3077A	2815A	1274C	932D
LSD(5%)	28.5	41.0	40.4	16.3

Values followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.

### 3.4. Conclusions

Crop management practices differed in their impact on crop yield and yield components. Among the stubble management treatments, burning crop stubble tended to increase the grain and biomass yield and yield components of wheat in most of the years, locations and production systems as compared to partial removal and complete retention. This environmental effect of straw retention on yield can be related to wet conditions early in the growing season. TKW responded positively to ZT or MT in most seasons. Other crop parameters, however, did not respond consistently to tillage in either the ox-plow or mechanised system trials. However, increased crop yields and yield components were more frequently associated with conventional tillage. Cropping sequence markedly affected the yields and yield components of wheat. The faba bean-based rotation consistently outperformed continuous wheat across all trials, locations and years.

## CHAPTER 4

### EFFECTS ON NITROGEN UPTAKE

#### 4.1 Introduction

Retention of crop residue can help to reduce wind and water erosion (Marsh & Carter, 1983), damage to the soil surface from raindrop impact, and evaporation of water from the soil surface. Crop stubble management may also affect the availability of soil nitrogen for crop growth and development. Stubble retention and late application of fertiliser nitrogen was reported to increase wheat yield (Bacon & Cooper, 1985), largely due to the effect of the N management. The effect of stubble management on N uptake resulted in superior N uptake relative to stubble incorporation (Bacon, 1987). When stubble was incorporated, N uptake decreased, resulting in a reduction in growth. High N accumulation associated with the incorporation of large quantities of residue at sowing could be due to the accumulation of phyto-toxic products of stubble degradation (Chou & Lin, 1976). Incorporation of straw has been shown to reduce the level of inorganic N in the soil over the short term (Black & Reitz, 1972; Powlson *et al.*, 1985). Nevertheless, some of the N immobilised by the stubble can be remobilized during the growing season and become available for uptake by the crop (Powlson *et al.*, 1985; Seligman *et al.*, 1986).

It is also important to understand how tillage affects soil nitrogen dynamics. In some environments, cultivation is known to affect the nitrogen relations of the soil through its effect on soil water status, the exposure of organic matter to decomposing organisms, and/or the vigour of crop growth (House *et al.*, 1984). Stein *et al.* (1987) showed that there was no overall effect of cultivation on nitrogen uptake, but House *et al.* (1984) stated that zero tillage led ultimately to a higher level of total soil nitrogen and increased nitrogen uptake relative to conventional tillage. Other studies also showed evidence of some increase in soil nitrogen supply as a result of zero tillage (Reeves & Ellington, 1974). Christensen *et al.* (1994) found that wheat response to N fertiliser varied with the production system and soil water level. Cereals under reduced or zero tillage may require additional N fertiliser to reach production levels similar to those attained under conventional tillage, due to a low extraction efficiency of available N (Rao & Dao, 1992).

A number of studies have indicated that the cultivation of  $N_2$  fixing legumes benefits the yield of a succeeding cereal crop (Senaraine & Hardarson, 1988). The residual N benefit from legumes is usually evident in the available soil mineral N pool. The soil N available for a subsequent crop is influenced by the amount of plant residues retained, the availability of N from the plant residues, the rate of mineralisation of soil organic matter, and the extent to which soil N was depleted by the preceding crop. Any differences in the contribution to soil N from preceding crops would, therefore, be largely due to differences in N release from live or decomposing roots and nodules (Papasylianou, 1987). The inclusion of grain legumes in cropping sequences generally increases soil nitrate, grain yield, total N accumulation, and N use efficiency of a subsequent wheat crop compared with a continuous wheat sequence with inorganic fertiliser applied (Badaruddin & Meyer, 1994).

In south-eastern Ethiopia, no previous study examined the integrated effects of stubble management, tillage and cropping sequence on wheat N uptake.

## 4.2 Results and Discussion

The results of the combined ANOVA across years of wheat N uptake for each of the four individual trials are presented in Tables 4.1 to 4.4.

The results of the combined ANOVA for the Kulumsa mechanised trial (Table 4.1) revealed that year, straw management by year, tillage by year, and cropping sequence by year effects comprised a high proportion of the total variability, reflecting pronounced environmental effects on N uptake by the wheat crop. However, at Asasa, in both the mechanised and ox-plow trials, the results of the combined ANOVA showed that year and cropping sequence by year comprised the major proportion of total variability (Tables 4.2 and 4.4). For the Kulumsa ox-plow trial, the year effect was the major component of total variability (Table 4.3).

**Table 4.1. Effect of crop management practices on wheat N uptake in the mechanised system trial at Kulumsa: ANOVA results across three years (1996-97, 1999).**

	GN%	SN%	GY	SY	GNU	SNU	TNU
Year (Y)	***		***	**	***	**	***
Straw management (SM)							
SM x Y	**		*		*		
Tillage (T)							
T x Y		*	**	**	*	*	*
SM x T							
SM x T x Y							
Cropping sequence (CS)			†	***			
CS x Y		†	*		**	*	***
SM x CS			**		**		*
SM x CS x Y						†	
T x CS				*		*	*
T x CS x Y			*				
SM x T x CS			*		*	*	**
SM x T x CS x Y	†					*	*
Mean	1.61	0.43	4570	6059	65.8	23.4	89.2
C.V. (%)	15.4	23.0	9.69	17.7	15.2	24.5	12.5

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

GN% = Grain N%; SN% = Straw N%; GY= Grain yield (kg/ha); SY= Straw yield (kg/ha); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha).

**Table 4.2. Effect of crop management practices on wheat N uptake in the mechanised system trial at Asasa: ANOVA results across three years (1996-97, 1999).**

	GN%	SN%	GY	SY	GNU	SNU	TNU
Year (Y)	**		*		***	**	**
Straw management (SM)							†
SM x Y							
Tillage (T)	*				*		***
T x Y		†	†			†	
SM x T							
SM x T x Y							
Cropping sequence (CS)						*	
CS x Y	***		***	***	***		***
SM x CS			†				
SM x CS x Y							
T x CS			†		†	†	*
T x CS x Y							
SM x T x CS				†			
SM x T x CS x Y							
Mean	1.62	0.36	3738	5340	52.2	22.1	74.3
C.V. (%)	7.42	25.1	10.6	15.9	13.7	30.1	15.9

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

GN% = Grain N%; SN% = Straw N%; GY= Grain yield (kg/ha); SY= Straw yield (kg/ha); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha).

**Table 4.3. Effect of crop management practices on wheat N uptake in the ox-plow system trial at Kulumsa: ANOVA results across three years (1996-97, 1999)**

	GN%	SN%	GY	SY	GNU	SNU	TNU
Year (Y)	**		**	**	***	**	***
Straw management (SM)							
SM x Y							
Tillage (T)							
T x Y							
SM x T	*						
SM x T x Y	*						
Cropping sequence (CS)							
CS x Y	†				*		**
SM x CS							
SM x CS x Y			*		**		*
T x CS							*
T x CS x Y	†	*	**				
SM x T x CS							
SM x T x CS x Y							
Mean	1.63	0.43	4849	5987	70.1	24.1	94.2
C.V. (%)	10.8	26.6	10.5	13.6	13.3	32.1	12.1

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

GN% = Grain N%; SN% = Straw N%; GY= Grain yield (kg/ha); SY= Straw yield (kg/ha); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha).

**Table 4.4. Effect of crop management practices on wheat N uptake in the ox-plow system trial at Asasa: ANOVA results across three years (1996-97, 1999)**

	GN%	SN%	GY	SY	GNU	SNU	TNU
Year (Y)	**	*	*		*	***	
Straw management (SM)							
SM x Y					*		*
Tillage (T)							
T x Y			*				
SM x T							
SM x T x Y							
Cropping sequence (CS)				†			
CS x Y			***	*	***	*	***
SM x CS		*					
SM x CS x Y		*					
T x CS							
T x CS x Y							
SM x T x CS							
SM x T x CS x Y							
Mean	1.60	0.41	3614	5309	50.2	20.4	70.6
C.V. (%)	11.7	21.5	1.40	16.3	14.3	32.6	18.2

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

GN% = Grain N%; SN% = Straw N%; GY= Grain yield (kg/ha); SY= Straw yield (kg/ha); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha).

#### 4.2.1 Straw management

Straw management (SM) significantly affected grain N% (GN%) during 1999, grain yield (GY) during 1996, 1997 and 1999, and grain N uptake (GNU) during 1999 in the Kulumsa mechanised trial (Table 4.5). The BURN treatment significantly increased GN%, followed by PARM, while RET gave the lowest GN%. Thus, stubble burning may have altered the pattern of N mineralisation.

In 1996, RET of crop stubble resulted in a higher GY of wheat relative to the BURN treatment, while PARM was intermediate. In 1997, partial removal of crop stubble gave the highest GY relative to RET, while BURN was intermediate. In 1999, BURN and PARM were equal, and both significantly outyielded the RET treatment (Table 4.5). Thus, across the three growing seasons, each treatment resulted in the highest GY of wheat at least once, reflecting an inconsistent effect of SM on GY.

In the 1999 Kulumsa mechanised trial, stubble burning increased GN%, suggesting higher N availability, and this was confirmed by the higher N uptake in the grain (Table 4.5). GY was higher for both BURN and PARM in 1999; GNU reflected a similar response, suggesting that the difference in GNU was at least partially if not wholly due to the higher GY for both treatments. Increased straw yield with burning suggested a higher early season availability of N which stimulated vegetative growth. Nitrogen taken up after anthesis is generally translocated directly to the grain. Wagger *et al.* (1985) found evidence of N immobilisation of recently mineralised N by wheat residue during the period of rapidly increasing soil temperature; this was followed by remineralisation later in the growing season.

In the Asasa, ox-plow trial a significant effect of SM on GNU and total N uptake (TNU) was observed during 1999; for both parameters, burning crop stubble markedly increased N uptake by wheat as compared to the PARM treatment (Table 4.5).

**Table 4.5. Effect of interaction of straw management by year on wheat N uptake in the mechanised and ox-plow system trials at Kulumsa and Asasa.**

SM	Kulumsa mechanised						Asasa ox-plow								
	GN%			GY			GNU			GNU			TNU		
	1996	1997	1999	1996	1997	1999	1996	1997	1999	1996	1997	1999	1996	1997	1999
Burn	1.79	1.68	1.57A	5294B	4296AB	3932A	82.9	63.1	53.0A	57.4	48.1	55.1A	74.9	68.2	85.8A
Removal	1.81	1.67	1.35B	5603AB	4540A	4013A	89.1	66.2	48.1A	50.8	47.6	42.6B	65.2	66.6	63.1B
Retention	1.77	1.74	1.12C	5864A	4090B	3499B	91.5	62.3	35.9B	---	---	---	---	---	---
LSD(5%)	0.16			389			9.34			6.72			10.7		

Values followed by the same or no letters within a column are not significantly different at the 5% level of the LSD test.

SM = Straw management; GN% = Grain N%; GY= Grain yield (kg/ha); GNU= Grain N uptake (kg/ha); TNU = Total N uptake (kg/ha).

#### 4.2.2 Tillage

The main effect of tillage significantly affected only GN%, GNU and TNU in the Asasa mechanised trial (Table 4.6). For each parameter, CT increased N content and uptake of the wheat crop relative to the MT treatment. Upon examining the year by tillage interaction means, it was observed that tillage significantly affected straw N% (SN%) during 1997, GY during 1996 and 1999, and SNU during 1997 in the Asasa mechanised trial (Table 4.7). In each instance of significance, the CT treatment outperformed the MT treatment. Tillage treatment also significantly affected SN% during 1996 and 1999, GY during 1997 and 1999, and straw yield (SY), GNU, straw N uptake (SNU) and TNU during 1997 in the Kulumsa mechanised trial (Table 4.7). SN% was increased by CT during 1996, but, during 1999, SN% was significantly higher under ZT. GY of wheat was higher under ZT during 1997, while CT resulted in the highest GY during 1999. Thus, an inconsistent pattern of response to tillage was observed in the current study. During 1997, the ZT treatment increased GY, SY, GNU, SN and TNU of the wheat crop, suggesting that the increased N uptake was primarily due to higher yield levels.

**Table 4.6. Effect of tillage practices on wheat N uptake in the mechanised system trial at Asasa: treatment means across three years (1996-97, 1999).**

	GN%	GNU	TNU
<b>Tillage</b>			
Conventional	1.66A	55.2A	78.9A
Minimum	1.58B	49.1B	69.6B

Values followed by the same or no letters within a column are not significantly different at the 5% level of the LSD test.

GN% = Grain N%; GNU = Grain N uptake (kg/ha) TNU = Total N uptake (kg/ha).

The cycling, metabolism, and availability of N to plants are greatly influenced by the degree and type of tillage. An indication of N deficiency and/or yield limitation in crops grown under no-till conditions have led several researchers to conclude that higher levels of fertiliser N are often required for no-till relative to plowed soils (Bakerman & de Wit, 1970; Bandel *et al.*, 1975). Reduced tillage of soils often results in a lower NO<sub>3</sub> content in the rooting zones as compared with that under conventional tillage (Dowdell & Cannell, 1975; Moody *et al.*, 1952 and Thomas *et al.*, 1973). The lower availability of N (and NO<sub>3</sub>) to crop plants under reduced tillage may be due to a more rapid downward movement of NO<sub>3</sub>, lower rates of nitrification and mineralisation, a greater rate of N immobilisation, and

**Table 4.7. Effect of interaction of tillage by year on wheat N uptake in the mechanised system trials at Kulumša and Asasa.**

Year	Kulumša: mechanised												Asasa: mechanised					
	SN%		GY		SY		GNU		SNU		TNU		SN%		GY		SNU	
	CT	ZT	CT	ZT	CT	ZT	CT	ZT	CT	ZT	CT	ZT	CT	MT	CT	MT	CT	MT
1996	0.51A	0.45B	5617	5557	7102	6931	89.4	86.2	31.6	27.5	121	114	0.38	0.39	4070A	3793B	19.5	17.3
1997	0.39	0.39	3987B	4661A	5310B	6638A	59.8B	67.9A	19.2B	23.9A	79B	92A	0.46A	0.38B	3287	3179	36.7A	29.9B
1999	0.38B	0.44A	4068A	3561B	5379	4994	49.4	41.9	18.3	20.1	68	62	0.29	0.30	4314A	3786B	15.1	14.2
LSD (5%)	0.054		338		684		7.70		4.20		10.2		0.059		268		3.93	

Values followed by the same or no letters within a row for each parameter are not significantly different at the 5% level of the LSD test.

SN% = Straw N%; GY = Grain yield (kg/ha); SY = Straw yield (kg/ha); GNU = Grain N uptake (kg/ha); TNU = Total N uptake (kg/ha);

CT = Conventional tillage; ZT = Zero tillage.

a limitation to the aerobic status of the soil resulting in greater losses of  $\text{NO}_3$  through denitrification.

### 4.2.3 Cropping sequence

The CS main effect exhibited a significant effect upon two parameters (i.e., GY and SY) in the Kulumsa mechanised trial and one parameter (i.e., SNU) in the Asasa ox-plow trial (Table 4.8). In each instance, the faba bean rotation increased the respective parameters of the wheat crop.

**Table 4.8. Effect of cropping sequence on wheat N uptake in the mechanised and ox-plow system trials at Kulumsa and Asasa: treatment means across three years (1996-97, 1999).**

Cropping sequence	Kulumsa mechanised		Asasa mechanised
	GY	SY	SNU
Faba bean	4863A	6405A	24.3A
wheat	4277B	5713B	19.9B

Values followed by the same or no letters within a column are not significantly different at the 5% level of the LSD test.

GY = Grain yield (kg/ha); SY = Straw yield (kg/ha); SNU = Straw N uptake (kg/ha).

CS also significantly affected SN% and SNU during 1996, GY from 1996 to 1999, and GNU and TNU during 1996 and 1999 in the Kulumsa mechanised trial at (Table 4.9), GN% during 1999, and GY, SY, GNU and TNU during 1996 and 1999 in the Asasa mechanised trial (Table 4.10), GN% during 1999, and GNU and TNU during 1996 and 1999 in the Kulumsa ox-plow trial (Table 4.10), and GY from 1996 to 1999, and SY, GNU, SNU and TNU during 1996 and 1999 in the Asasa ox-plow trial (Table 4.9). In each instance of significance, the faba bean rotation significantly increased wheat yield and N uptake parameters, reflecting a consistent effect of faba bean rotation in increasing the yield and N uptake of wheat.

Several studies indicated that the cultivation of an  $\text{N}_2$  fixing legume produces a beneficial effect on the yield of a succeeding cereal (Senaraine & Hardarson, 1988). For the subsequent crop, it is important that the residual N benefit from the legume is evident in the pool of available soil mineral N. Senaraine & Hardarson (1988) reported that the N benefit to subsequent crops following grain legumes was due to a lower uptake of soil N by legumes relative to cereals, and a carryover of N from the legume residue. Both factors resulted in a greater uptake of soil N by the subsequent cereal crop compared to cereals

**Table 4.9. Effect of interaction of cropping sequence by year on wheat N uptake in the mechanised and ox-plow system trials at Kulumsa and Asasa.**

Year	Kulumsa mechanised										Asasa ox-plow									
	SN%		GY		GNU		SNU		TNU		GY		SY		GNU		SNU		TNU	
	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH
1996	0.53A	0.42B	6034A	5139B	99A	77B	34A	25B	133A	102B	4278A	3354B	5957A	4508B	61A	47B	19A	13B	80A	60B
1997	0.40	0.39	4500A	4118B	66	62	23	20	89	82	3287A	3021B	5626	5199	49	47	20	19	69	66
1999	0.42	0.40	4055A	3573B	50A	41B	20.9	17.4	71A	58B	4553A	3192B	6166A	4399B	61A	36B	32A	19B	93A	56B
LSD(5%)	0.067		299		6.75		3.88		7.54		246		730		6.05		5.60		10.8	

Values followed by the same or no letter within a row for each parameter are not significantly different at the 5% level of the LSD test.

SN = Straw N%; GY = Grain yield (kg/ha); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SY = Straw yield (kg/ha); FB = Faba bean rotation with wheat (1 year in 3); WH = Continuous wheat.

**Table 4.10. Effect of interaction of cropping sequence by year on wheat N uptake in the mechanised and ox-plow system trials at Kulumsa and Asasa.**

Year	Asasa mechanised										Kulumsa ox-plow					
	GN%		GY		SY		GNU		TNU		GN%		GNU		TNU	
	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH
1996	1.71	1.78	4532A	3331B	5857A	4666B	68.0A	51.9B	88.8A	67.9B	1.90	1.76	99.5A	83.6B	130A	107B
1997	1.93	1.93	3210	3256	5580	5296	53.5	54.3	87.6	86.8	1.61	1.58	68.1	65.1	97	94
1999	1.27A	1.09B	4861A	3239B	6367A	4274B	53.9A	31.3B	71.8A	42.7B	1.61A	1.33B	61.5A	42.9B	80A	57B
LSD(5%)	0.079		85.1		576		4.69		7.99		0.148		7.87		9.63	

Values followed by the same or no letters within a row for each parameter are not significantly different at the 5% level of the LSD test.

GN% = Grain N%; GY = Grain yield (kg/ha); GNU = Grain N uptake (kg/ha); TNU = Total N uptake (kg/ha); FB = Faba bean rotation with wheat

(1 year in 3); WH = Continuous wheat.

grown after non-legumes. Petch & Smith (1985) suggested that the residual value of a legume might not be related only to the lower amount of soil N removed by the legume.

The increased yield of cereal crops following legumes has been attributed mainly to changes in soil N content (Baldock *et al.*, 1981). However, the beneficial effects of including grain legumes in a cropping sequence can also be attributed to changes in other soil properties (Barber, 1972), reduced toxic substances in crop residues (Barber, 1972), reduced disease and insect problems (Baldock *et al.*, 1981), or the release of growth promoters from the legume residues (Ries *et al.*, 1977). The amount of N partitioned to grain from the vegetative canopy is a major factor affecting the protein concentration of wheat grain. The increased amount of N partitioned to the grain of wheat following a legume crop compared with continuous wheat was probably due to increased N in the soil, but could also be due to a prolonged period of supply of N to the wheat crop from decomposing legume residues (Bailey, 1982). It appears from the current study that the inclusion of faba bean in the cropping sequence can stabilise the yield and quality of the subsequent wheat crop.

#### 4.2.4 Interactions among crop management factors

A significant effect of SM by CS interaction was observed for GY, GNU and TNU in the Kulumsa mechanised trial, for GY in the Asasa mechanised trial, and for SN% in the Kulumsa ox-plow trial (Table 4.11). In the two mechanised trials, each significant parameter exhibited lower levels in general under continuous wheat cf. wheat in rotation with faba bean. However, for wheat in the faba bean rotation, there was no advantage apparent for the BURN treatment relative to the PARM or RET treatments. In fact, GY and GNU in the Kulumsa mechanised trial were actually lower for the BURN plus FB combination relative to either RET or PARM in combination with FB. However, under continuous wheat, BURN resulted in significantly higher wheat parameter values relative to one or both of the other SM treatments.

The interaction observed for SN% in the Kulumsa ox-plow trial was less clear (Table 4.11). SN% in the FB-BURN combination was higher than the WH-BURN and FB-PARM combinations, while WH-PARM was intermediate.

**Table 4.11. Effect of interaction of straw management by cropping sequence on wheat N uptake in the mechanised and ox-plov system trials at Kulumsa and Asasa.**

Straw management	Kulumsa mechanised						Asasa mechanised		Kulumsa ox-plov	
	GY		GNU		TNU		GY		SN%	
	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH
Burn	4622B	4392B	67.2BC	65.4C	94A	86B	4294A	3636B	0.47A	0.37B
Removal	5030A	4466B	74.8A	60.7C	99A	82BC	4233A	3144C	0.39B	0.41AB
Retention	4937A	4032C	72.5AB	53.9D	100A	75C	4075A	3046C	---	---
LSD(5%)	242		6.75		7.54		268		0.062	

Values followed by the same letters within each parameter are not significantly different at the 5% level of the LSD test.

GY = Grain yield (kg/ha); GNU = Grain N uptake (kg/ha); TNU = Total N uptake (kg/ha); FB = Faba bean rotation with wheat (1 year in 3); WH = Continuous wheat.

**Table 4.12. Effect of interaction of tillage by cropping sequence on wheat N uptake in the mechanised and ox-plov system trials at Kulumsa and Asasa**

Tillage	Kulumsa mechanised						Asasa mechanised						Kulumsa ox-plov			
	SY		SNU		TNU		GY		GNU		SNU		TNU			
	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH	FB	WH		
CT	6038B	5822B	24.1B	22.0BC	95A	84B	4239A	3540B	60.3A	50.1B	24.7A	22.9A	84.9A	72.9B	103A	101A
ZT/MT	6772A	5603B	28.1A	19.5C	100A	78B	4161A	3110C	56.6A	41.6C	23.9A	16.9B	80.5A	58.6C	89B	83B
LSD(5%)	592		3.17		6.15		219		3.79		3.68		6.53		7.86	

Values followed by the same letters within a parameter are not significantly different at the 5% level of the LSD test.

SY = Straw yield (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha); GY = Grain yield (kg/ha); GNU = Grain N uptake (kg/ha); CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage; FB = Faba bean rotation with wheat (1 year in 3); WH = Continuous wheat.

Tillage by CS interaction was significant for SY, SNU and TNU in the Kulumsa mechanised trial, GY, GNU, SNU and TNU in the Asasa mechanised trial, and TNU in the Kulumsa ox-plow trial (Table 4.12). For the two mechanised trials, the highest parameter levels were generally obtained from the combination of FB with reduced tillage, while the lowest parameter levels were measured in continuous wheat under reduced tillage. Thus, yields and N uptake levels diverged dramatically under reduced tillage in response to cropping sequence but under conventional tillage, CS had much less impact on yields and N uptake levels.

The tillage by CS interaction effect reflected in TNU in the Kulumsa ox-plow trial was less clear (Table 4.12). The combination of FB + CT resulted in the highest TNU, while WH + MT produced the lowest TNU.

A significant effect of SM by tillage interaction was observed only for GN% in the Kulumsa ox-plow trial. PARM under MT resulted in a lower GN% than the other three treatment combinations (Table 4.13).

**Table 4.13. Effect of interaction of straw management by tillage on grain N% of wheat in the ox-plow system trial at Kulumsa.**

Straw management	Tillage	
	Conventional	Minimum
Burn	1.65A	1.64A
Remove	1.66A	1.56B
LSD(5%)	0.056	

Values followed by the same letter are not significantly different at the 5% level of the LSD test.

#### 4.2.5 Effect of treatments on N uptake by faba bean

Faba bean yield and N parameters were measured during the break crop cycle of 1998 (Tables 4.14 and 4.15). In general, few parameters of the faba bean crop exhibited a response to the SM and tillage treatments. The SM main effect significantly affected SNU in the Kulumsa mechanised trial, GY, SY and SNU in the Kulumsa ox-plow trial, and SY in the Asasa ox-plow trial (Tables 4.14 and 4.15). In the Kulumsa mechanised trial, GY was lower for RET than for PARM, while BURN was intermediate and equal to the other two treatments. For all significant parameters in the Kulumsa ox-plow trial, the BURN

**Table 4.14. Crop management effect on faba bean N uptake in the mechanised system trials at Kulumsa and Asasa in 1998: treatment means**

Straw management	Kulumsa mechanised							Asasa mechanised						
	GN%	SN%	GY	SY	GNU	SNU	TNU	GN%	SN%	GY	SY	GNU	SNU	TNU
Burn	3.44	0.96	2996	3789	89.1	33.9AB	123	4.47	0.77	2958	4212	115	32.1	147
Removal	3.6	1.07	2879	5407	83.8	51.3A	135	4.48	0.80	3219	3789	126	28.1	154
Retain	3.42	0.99	2465	2706	74.0	24.8B	99	4.00	0.88	3085	3362	106	28.1	135
LSD(5%)						26.1								
<b>Tillage</b>														
Conventional	3.45	1.05	2968	3394	89.9	33.3	123	4.47	0.87	3116	3749	122A	31.3	153A
Minimum	3.35	0.96	2574	4541	74.7	40.1	115	4.17	0.76	3058	3826	110B	27.6	138B

Values within a column (for each management factor) followed by the same or no letters do not differ significantly at the 5% level of the LSD test.

GN% = Grain N%; SN% = Straw N%; GY = Grain yield (kg/ha); SY = Straw yield (kg/ha); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha).

**Table 4.15. Crop management effect on faba bean N uptake in the ox-plow system trials at Kulumsa and Asasa in 1998: treatment means**

Straw management	Kulumsa ox-plow							Asasa ox-plow						
	GN%	SN%	GY	SY	GNU	SNU	TNU	GN%	SN%	GY	SY	GNU	SNU	TNU
Burn	3.69	0.82	3218A	4414A	104	32.7A	137	3.96	0.87	3298	3061B	114	23.9	138
Removal	3.69	0.87	2916B	2799B	94	21.8B	116	3.88	0.92	3574	3644A	122	30.2	152
<b>Tillage</b>														
Conventional	3.65	0.89	2803	3039	90	24.2	114	3.91	1.00A	3177	3293	108	30.2	138
Minimum	3.73	0.80	3331	4175	108	30.3	139	3.91	0.78B	3696	3411	127	23.9	151

Values within a column (for each management factor) followed by the same or no letters do not differ significantly at the 5% level of the LSD test.

GN% = Grain N%; SN% = Straw N%; GY = Grain yield (kg/ha); SY = Straw yield (kg/ha); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha).

treatment resulted in higher parameter levels (Table 4.15), while in the Asasa ox-plow trial, the PARM treatment increased the SY of faba bean cf. the BURN treatment.

Tillage treatment significantly affected GNU and TNU in the mechanised trial at Asasa (Table 4.14), and SN% in the ox-plow trial at Asasa (Table 4.15). For each significant parameter in both trials, CT resulted in higher parameter levels for the faba bean crop (Tables 4.14 and 4.15).

### 4.3 Conclusions

Crop management practices differed markedly in their impact on wheat N uptake across seasons and trials. Burning of stubble tended to enhance wheat N uptake in contrast to partial removal or retention of the straw. The effect of tillage also varied, although CT tended to elevate the measured parameters of the wheat crop relative to ZT or MT. In contrast, CS exhibited more consistent effects on the yield and N uptake of the wheat crop, suggesting that the faba bean break crop dramatically enhanced soil N status thereby benefiting the subsequent cereal crop. Thus, in order to increase the yield and N content of wheat grain and straw, the inclusion of a legume crop such as faba bean can sustain soil N levels for the succeeding cereal crops.

## CHAPTER 5

### EFFECTS ON SOIL PROPERTIES

#### 5.1 Soil physical properties

##### 5.1.1 Introduction

Soil physical and chemical properties critically influence crop production. Cropping practices that exert a significant impact upon soil properties include management of crop residues, tillage practices, and crop rotational systems (Aulakh & Gill, 1988; Stobbe, 1990; Sweeney & Moyer, 1995).

Retention of crop residue on the soil surface conserves soil organic matter and water especially when coupled with conservation tillage (Griffith *et al.*, 1986). Also, maintenance of crop residue cover reduces soil erosion by minimizing raindrop impact on the soil surface (Aulakh & Gill, 1988). Although stubble burning is generally viewed as undesirable, resulting in a deterioration of soil physical and chemical conditions over the long-term (Rasmussen & Rohde, 1988), burning can result in short-term yield increments by reducing crop disease and weed propagules, particularly in the shallow surface layer of the soil, and by increasing the rate of nutrient release from the soil (Rasmussen *et al.*, 1986).

Tillage practices affect multiple soil physical and chemical properties, including soil water content, mechanical resistance, organic matter (OM) content, and soil nitrogen (N) levels. As the extent of soil disturbance by tillage is increased, soil structural deterioration and erosion are exacerbated, especially on erosion-prone soils. Conservation tillage including minimum (MT) and zero tillage (ZT), can reduce such deleterious soil effects (Stobbe, 1990). However, conservation tillage has frequently been observed to increase soil compaction, as measured by penetration resistance (PR), particularly in the surface layer of soils with high clay content (Izaurrealde *et al.*, 1986; Sweeney & Moyer, 1995; Unger, 1996). Compaction in the surface layers of soil has been reported by some authors as having an adverse effect on bread wheat grain yield (Cornish & Fettell, 1977; Oussible *et al.*, 1993), while other studies failed to demonstrate a consistent association between

tillage-induced compaction and the yield of wheat (Agrawal *et al.*, 1975; Feldman & Domier, 1970; Unger & Fulton, 1990; Voorhees *et al.*, 1985).

Soil physical and chemical properties may also be modified by the crop species included in a rotational system. Studies on the effects of crop rotation have indicated that, regardless of the tillage system involved, rotations including dicotyledonous crops tend to reduce soil compaction (Griffith *et al.*, 1986).

In Ethiopia, the long-term effects of stubble management (SM), tillage, and cropping sequence (CS) practices on physical soil properties have not been adequately studied. Thus, this study was initiated to examine the effects of integrated crop management practices on soil PR and wheat yield in the south-eastern highlands of Ethiopia.

## 5.1.2 Result and Discussion

### 5.1.2.1 Treatment effects on soil penetrometer resistance

The results of the ANOVA of soil penetrometer resistance (PR) data combined over years for each of the four crop management trials are presented in Table 5.1.  $\text{Log}_{10}$  transformed PR data were normally distributed, and trial C.V.-values fell within an acceptable range of 3.81 to 4.22% (Table 5.2).

The year effect on soil PR was highly significant for the four trials (Table 5.1). For each trial, the first PR measurement recorded was the lowest (i.e., the 1994 data for the Kulumsa trials and the 1996 data for the Asasa trials) while the latest PR measurement recorded during 1999, was the highest, suggesting a trend for PR to increase over seasons (Table 5.2).

The main effects of tillage and depth on PR were significant ( $P < 0.05$ ) in three and four trials, respectively, while the main effects of SM and CS were not significant in any of the trials (Table 5.1). Two-way interactions involving soil depth exhibited a high frequency of significance ( $P < 0.05$ ). Tillage, SM, and CS practices interacted with depth in four, two and

**Table 5.1. Results of combined analysis of variance over years<sup>a</sup> for penetration resistance (log<sub>10</sub> kPa) measured in the trials conducted at Asasa and Kulumsa.**

Source of Variation	Ox-plow			Mechanized		
	d.f.	MS <sup>b</sup>		d.f.	MS <sup>b</sup>	
		Asasa	Kulumsa		Asasa	Kulumsa
Year (Y)	3	2.26***	3.05***	3	1.76***	6.84***
Residual	8	0.117	0.042	8	0.092	0.058
Stubble management (SM)	1	0.001	0.010	2	0.218 <sup>c</sup>	0.033
Y x SM	3	0.066	0.117†	6	0.247***	0.120
Residual	8	0.025	0.037	16	0.025	0.062
Tillage (T)	1	0.123	0.917**	1	2.08*	3.71***
Y x T	3	0.043	0.074	3	0.167*	0.151†
SM x T	1	0.000	0.030	2	0.012	0.073
Y x SM x T	3	0.012	0.041	6	0.017	0.043
Residual	16	0.059	0.076	24	0.049	0.058
Cropping sequence (CS)	1	0.024	0.028	1	0.128	0.005
Y x CS	3	0.042	0.043	3	0.071	0.024
SM x CS	1	0.031	0.019	2	0.012	0.046
Y x SM x CS	3	0.011	0.036	6	0.030	0.052
T x CS	1	0.026	0.006	1	0.000	0.043
Y x T x CS	3	0.046	0.051	3	0.145†	0.020
SM x T x CS	1	0.001	0.028	2	0.022	0.080
Y x SM x T x CS	3	0.016	0.019	6	0.098	0.077
Residual	32	0.022	0.051	48	0.060	0.065
Depth (D)	5	7.34***	7.23***	5	9.70***	6.46***
Y x D	15	0.118***	0.219***	15	0.085***	0.209***
SM x D	5	0.038*	0.018	10	0.043 <sup>c</sup>	0.037*
Y x SM x D	15	0.018	0.023	30	0.029*	0.015
T x D	5	0.050**	0.094†	5	0.201**	0.301***
Y x T x D	15	0.017	0.041**	15	0.033*	0.036**
SM x T x D	5	0.014	0.009	10	0.019	0.038*
Y x SM x T x D	15	0.010	0.022	30	0.016	0.011
CS x D	5	0.017	0.006	5	0.034†	0.041*
Y x CS x D	15	0.013	0.011	15	0.018	0.023
SM x CS x D	5	0.030†	0.009	10	0.005	0.018
Y x SM x CS x D	15	0.015	0.013	30	0.022	0.011
T x CS x D	5	0.034†	0.006	5	0.028	0.006
Y x T x CS x D	15	0.020	0.028†	15	0.028†	0.017
SM x T x CS x D	5	0.009	0.006	10	0.014	0.016
Y x SM x T x CS x D	15	0.017	0.017	30	0.013	0.009
Residual	320	0.016	0.019	480	0.018	0.018

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

<sup>a</sup> PR measured in the trials conducted at Asasa and Kulumsa during 1996 to 1999, inclusive, and during 1994 at Kulumsa.

<sup>b</sup> Mean square values.

<sup>c</sup> Indicates a mean square value that is non-significant in comparison to the corresponding significant interaction with year (i.e., considering year as a random factor).

two trials, respectively. None of the two-way interactions among tillage, CS and SM were significant in any of the four trials.

Soil PR increased significantly ( $P < 0.001$ ) across each 5 cm increment from the surface layer to the 25-30 cm depth interval (Tables 5.1. and 5.2). Mean PR values were virtually identical at Kulumsa and Asasa, despite the markedly higher clay content in the soil at Kulumsa (Table 5.2).

Tillage practice significantly affected soil PR in both mechanized trials and one ox-plow trial (Tables 5.1 and 5.2). In the trials exhibiting a significant tillage effect, PR was consistently increased under conservation tillage practices (i.e., ZT in the Kulumsa mechanized trial and MT for the other two trials). Tillage by year interaction was significant in both mechanized trials (Table 5.1). In the Asasa trial, MT exhibited a higher PR than conventional tillage in 3 out of 4 years, while in the Kulumsa trial, PR was significantly higher under ZT cf. conventional practice in 4 out of 5 years. During 1999 at both sites, there was no difference in PR between the tillage treatments. Studies conducted elsewhere have demonstrated an increase in PR as a consequence of conservation tillage (Izaurrealde *et al.*, 1986; Sweeney & Moyer, 1995; Unger, 1996), but increased PR was not consistently associated with a reduction in wheat grain yield (Izaurrealde *et al.*, 1986; Unger & Fulton, 1990). Of the 18 site-season data sets included in the current report (i.e., five seasons for each trial at Kulumsa and four seasons for each trial at Asasa), tillage had a significant effect on wheat grain yield in only eight seasons (Table 3.2). In six site-seasons, wheat under conventional tillage yielded significantly more grain cf. wheat under MT or ZT. In two site-seasons, wheat under MT or ZT yielded significantly more than wheat under conventional tillage. Furthermore, of the eight site-seasons exhibiting a significant effect of tillage on wheat grain yield, only three exhibited a significant effect of tillage on PR.

Although the main effect of SM did not significantly affect PR in any of the four trials, SM by year interaction was significant in two of the trials (Table 5.1). In the Asasa mechanized trial, the stubble burning treatment exhibited a significantly lower PR than either partial removal or complete retention in 1996; in 1998, the burn and retention treatments exhibited lower PR than partial removal; in 1999, retention was associated with a lower PR

than stubble burning, while partial removal was intermediate and not significantly different from either. The association of a higher PR value with complete stubble retention in 1996 contradicts a previous report of the favorable effect of surface residues in reducing soil

**Table 5.2. Treatment main effect, year and depth means for penetration resistance ( $\log_{10}$  kPa) measured in the trials conducted at Asasa and Kulumsa.**

	Ox-plow		Mechanized	
	Asasa	Kulumsa	Asasa	Kulumsa
<b>Year</b>				
1994	-	3.09 C	-	2.96 C
1996	3.13 C	3.40 A	3.16 C	3.36 A
1997	3.27 B	3.21 B	3.30 B	3.24 B
1998	3.26 B	3.18 B	3.25 B	3.36 A
1999	3.44 A	3.43 A	3.38 A	3.39 A
LSD(0.05)	0.093	0.054	0.067	0.052
<b>Stubble management</b>				
Burn	3.27	3.26	3.25	3.27
Removal	3.28	3.27	3.30	3.27
Retention	-	-	3.27	3.25
LSD(0.05)	NS	NS	NS	NS
<b>Tillage</b>				
Conventional	3.26	3.23 B	3.22 B	3.20 B
Zero or Minimum <sup>a</sup>	3.29	3.30 A	3.32 A	3.32 A
<b>Cropping sequence</b>				
Faba bean rotation	3.27	3.27	3.29	3.26
Continuous wheat	3.28	3.26	3.26	3.27
<b>Depth (cm)</b>				
0-5	2.86 F	2.85 F	2.89 F	2.95 F
5-10	3.08 E	3.12 E	3.10 E	3.17 E
10-15	3.23 D	3.27 D	3.22 D	3.25 D
15-20	3.38 C	3.36 C	3.36 C	3.32 C
20-25	3.50 B	3.44 B	3.47 B	3.39 B
25-30	3.60 A	3.53 A	3.61 A	3.50 A
LSD(0.05)	0.036	0.035	0.062	0.028
Mean	3.27	3.26	3.27	3.26
C. V.(%)	3.81	4.22	4.06	4.07

Values within each factor within a column followed by the same letter or no letters are not significantly different at the 5% level of the LSD test.

<sup>a</sup> ZT for Kulumsa mechanized; MT for the other trial.

crust strength and the bulk density of surface soil layers under conservation tillage (Unger & Fulton, 1990). In the Kulumsa ox-plow trial, soil PR was lower following stubble burning cf. partial removal in 1998. Thus, across the 18 site-season data sets, the effect of SM on PR was seldom significant and, when significant, the effect was not consistent. In contrast with the relatively low frequency of the significance of the effect of SM on PR, SM affected wheat grain yield in nine site-seasons. In the majority of these cases, the stubble burning treatment exhibited the highest grain yields.

CS did not exhibit a significant effect on soil PR in any of the four trials (Tables 5.1 and 5.2). Chan & Heenan (1996) reported significant effects of CS on soil PR, particularly contrasting rotations of cereals with dicotyledonous crops vs. cereal-dominated rotations, while McFarland *et al.* (1990) did not observe differences in soil PR related to CS. Of the 18 site-seasons included in the current study, CS had a significant effect on wheat grain yield in 11 (Table 3.3). In each case, wheat in rotation with faba bean (i.e., including instances of both the first and the second consecutive wheat crop following faba bean) yielded significantly more than continuous wheat.

In the following paragraphs, all of the significant ( $P < 0.1$ ) two-way treatment interactions with depth are presented (Tables 5.3 to 5.5) and discussed.

For each of the four trials, tillage by depth interaction, averaged across years, exhibited a convergence type of interaction (Table 5.3) The conservation tillage treatments consistently exhibited higher soil PR values in the uppermost soil layers in comparison with conventional tillage, but, approaching the 25-30 cm layer, the tillage treatments converged upon a common and maximal PR value. The data also revealed that the significantly higher PR values under conservation tillage extended deeper into the soil profile for the mechanized trials. In both mechanized trials, conventional tillage exhibited lower PR values than conservation tillage in the top five soil layers. In contrast, the ox-plow trials exhibited higher PR values under MT in the uppermost one and three soil layers at Asasa and Kulumsa, respectively.

Although significant in three of the four trials, the year by tillage by depth interactions (Table 5.1) accounted for a smaller proportion of the total sum of squares for each

Table 5.3. Effects of interaction of tillage by depth on penetration resistance ( $\log_{10}$  kPa) in the trials conducted at Asasa and Kulumsa.

Depth (cm)	Asasa ox-plow		Kulumsa ox-plow		Asasa mechanized		Kulumsa mechanized	
	Conv <sup>a</sup>	MT	Conv	MT	Conv	MT	Conv	ZT
0-5	2.82 B	2.89 A	2.79 B	2.91 A	2.86 B	2.92 A	2.89 B	3.02 A
5-10	3.06	3.09	3.06 B	3.19 A	3.03 B	3.16 A	3.06 B	3.28 A
10-15	3.24	3.22	3.22 B	3.32 A	3.12 B	3.32 A	3.16 B	3.34 A
15-20	3.39	3.37	3.34	3.37	3.29 B	3.42 A	3.27 B	3.37 A
20-25	3.51	3.49	3.43	3.45	3.43 B	3.51 A	3.37 B	3.41 A
25-30	3.61	3.59	3.52	3.53	3.61	3.60	3.49	3.50
LSD(0.05)	0.051		0.049		0.044		0.039	
Prob.	**		†		**		***	

†, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

Values within a specific depth interval for each trial followed by a unique letter are significantly different at the 5% level of the LSD test.

<sup>a</sup> Conv = Conventional tillage; MT = Minimum tillage; ZT = Zero tillage.

ANOVA than the corresponding tillage by depth interaction. Where significant, the three way interactions indicated the presence of a crossover type of interaction effect in a particular site-season combination. For example, in the mechanized trial at Kulumsa in 1997, tillage by depth interaction ( $P < 0.001$ ) was characteristic of the convergence type (Fig. 5.1). ZT exhibited higher soil PR values cf. conventional tillage in the four uppermost soil layers, below the 20 cm depth differences among tillage treatments were not significant. An interaction of the crossover type was only observed in the mechanized trial at Kulumsa during 1994 (Fig. 5.1). From 0-15 cm in depth, soil PR was greater under ZT, but from 20-30 cm in depth, soil PR was greater under conventional tillage, presumably reflecting a slight plow-pan effect. Unger (1996) reported that, under ZT, soil PR increases were limited to the upper 15 cm of the soil profile, while Sweeney & Moyer (1995) reported a crossover effect at about the 10 cm depth in the soil profile.

The interaction of SM by depth exerted a significant effect on soil PR in two trials, while a significant year by SM by depth interaction obscured the SM by depth interaction in a third trial (Table 5.1). As was the case for the interaction effects of SM by year, the SM by depth interaction effects were not consistent. In the Kulumsa mechanized trial, stubble burning resulted in the lowest soil PR in the 5-10 cm layer and the highest PR values in the 20-25 and 25-30 cm layers (Table 5.4). Complete stubble retention resulted in the lowest PR in the 25-30 cm layer and intermediate values in the 5-10 and 20-25 layers. The 0-5, 10-15 and 15-20 cm layers exhibited no differences in PR due to SM. In the Asasa ox-plow trial, only the 0-5 cm layer exhibited an effect of SM where stubble burning was associated with a lower PR than partial removal. Thus, the apparent effect of burning crop residue on soil PR was not consistent, and, inexplicably, the effect was not confined to the shallow surface layer of soil which is normally the zone affected by burning (Rasmussen *et al.*, 1986). There was also no consistent trend apparent for the CS by depth interaction. For both mechanized trials, which exhibited significance for this interaction, the effect on PR was confined to the 0-5 cm soil layer. However, the effect was manifested in opposite directions with the lowest PR observed under continuous wheat in the Asasa trial vs. the highest PR measured under continuous wheat in the Kulumsa trial (Table 5.5).

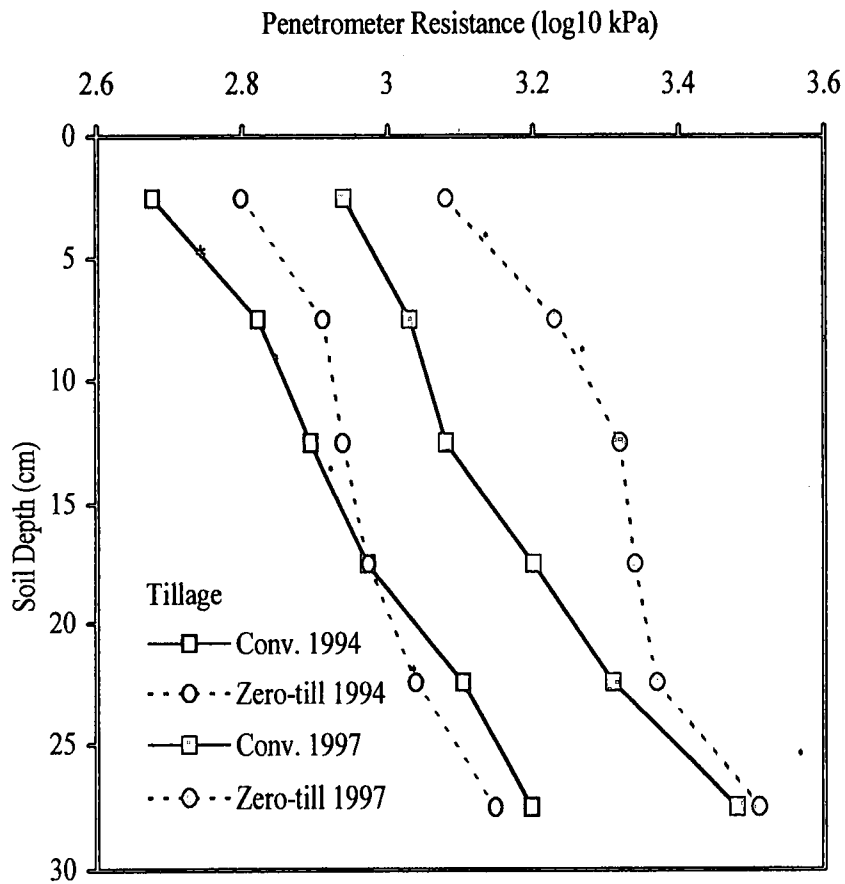


Figure 5.1. The effect of interaction between tillage practice and measurement depth on penetration resistance (log<sub>10</sub> kPa) in 1994 ( $P < 0.001$ ,  $LSD_{0.05} = 0.035$ ) and 1997 ( $P < 0.001$ ,  $LSD_{0.05} = 0.080$ ) in the Kulumsa mechanized trial.

**Table 5.4. Effects of interaction of stubble management by depth on penetration resistance ( $\log_{10}$  kPa) in the trials conducted at Asasa and Kulumsa:**

Depth (cm)	Asasa ox-plow		Kulumsa mechanized		
	Burn	Remove	Burn	Remove	Retain
0-5	2.82 B	2.89 A	2.95	2.95	2.97
5-10	3.06	3.09	3.15 B	3.20 A	3.16 AB
10-15	3.24	3.22	3.24	3.27	3.25
15-20	3.39	3.37	3.33	3.32	3.30
20-25	3.51	3.49	3.43 A	3.37 B	3.38 AB
25-30	3.61	3.59	3.54 A	3.49 A	3.47 B
LSD(0.05)	0.051		0.048		
Prob.	*		*		

\* Statistically significant at  $0.01 < P < 0.05$ .

Values within a specific depth interval for each trial followed by the same letter(s) or no letters are not significantly different at the 5% level of the LSD test.

**Table 5.5. Effects of interaction of cropping sequence by depth on penetration resistance ( $\log_{10}$  kPa) in the trials conducted at Asasa and Kulumsa**

Depth (cm)	Asasa mechanized		Kulumsa mechanized	
	Faba bean rotation	Continuous wheat	Faba bean rotation	Continuous wheat
0-5	2.93 A	2.85 B	2.93 B	2.98 A
5-10	3.10	3.10	3.15	3.19
10-15	3.24	3.20	3.26	3.24
15-20	3.36	3.35	3.31	3.32
20-25	3.48	3.46	3.40	3.38
25-30	3.61	3.60	3.51	3.49
LSD(0.05)	0.044		0.039	
Prob.	†		*	

†, \* Statistically significant at  $0.1 < P < 0.05$  and  $0.01 < P < 0.05$ , respectively.

Values within a specific depth interval for each trial followed by a unique letter are significantly different at the 5% level of the LSD test.

### 5.1.2.2 Regression of grain yield on penetrometer resistance

The results of the simultaneous regression of the mean wheat grain yield for each treatment within each of the 18 site-season data sets, on the corresponding mean PR measurement, revealed that seven of the 12 regression coefficients used in the model were significant (Table 5.6). Inclusion of the seven significant components in the multiple

regression model explained a highly significant proportion of the variation in wheat grain yield (i.e., adjusted multiple  $R^2 = 0.856$ ,  $F_{7,172} = 152.5$ ,  $P < 0.001$ ).

The regression coefficients associated with the indicator variables (Neter *et al.*, 1990), used to represent years, locations, and production systems indicated that year and location effects were highly significant ( $P < 0.001$ ), while the effect of production system on grain yield was non-significant (Table 5.6). Summarizing the 18 site-seasons, respective mean wheat grain yields (i.e., based on the 180 treatment means across all trials) were:

- 1093, 4786, 3850, 2923, and 3919 kg ha<sup>-1</sup> in 1994, 1996, 1997, 1998, and 1999
- 3224 and 3567 kg ha<sup>-1</sup> in Kulumsa and Asasa
- 3317 and 3418 kg ha<sup>-1</sup> in mechanized and ox-plow systems

The regression coefficients associated with the quantitative variables, representing log<sub>10</sub> transformed PR at six depths of measurement, indicated that only PR values at the 0-5 and 20-25 cm depths in the soil profile were significantly related to wheat grain yield (Table 5.6): PR at the 0-5 cm depth was negatively related to grain yield while PR at the 20-25 cm depth was positively related to grain yield. Several authors have reported both positive and negative relationships between soil compaction and wheat grain yield (Agrawal *et al.*, 1975; Feldman & Domier, 1970; Voorhees *et al.*, 1985), depending on the depth of the compacted layer and reflecting differences in soil structure, soil water content and seasonal precipitation. Compaction in the shallow surface layer can reduce grain yields under moist conditions through a negative impact on crop germination (Talha *et al.*, 1978) and early tiller production (Pollard & Elliott, 1978). Conversely, compacted soils frequently exhibit improved soil water status under relatively dry conditions due to reduced internal hydraulic conductivity (Reicosky *et al.*, 1981). Under such conditions, compaction can increase both the grain yields and water use efficiency of wheat (Voorhees *et al.*, 1985). In the agro-ecological zone represented in the current study, wheat germinates under relatively moist soil conditions (i.e., at the start of the main rainy season), but is commonly exposed to terminal drought stress. Presumably, the contrasting effects of soil compaction at the two depths noted in the current study reflect this seasonal dichotomy where under moist conditions early in the crop cycle, compaction in the shallow surface layer of the soil inhibits crop development as reported by Voorhees *et al.* (1985). Under the influence of

terminal drought stress late in the crop cycle, however, compaction deeper in the soil profile enhances water use efficiency (Reicosky *et al.*, 1981; Voorhees *et al.*, 1985).

No clear definition of the critical or threshold PR value limiting wheat root growth exists, however, using a flat-tipped penetrometer, Busscher & Sojka (1990) referred to PR values of 1 and 2 Mpa as root reducing and restricting limits, respectively. A 2 Mpa value corresponds to a  $\log_{10}$  transformed PR value of 3.301, a value exceeded in many of the trials included in the current report, particularly in the 20-30 cm depth in the soil profile.

**Table 5.6. Values of coefficients derived from the simultaneous regression of mean wheat grain yield for each treatment within each trial on  $\log_{10}$  transformed PR means for six depth intervals, across five years, two sites, and two crop production systems.**

Coefficient <sup>a</sup>	Factor	Value	Probability
$\beta_1$	PR <sub>1</sub>	-775	**
$\beta_5$	PR <sub>5</sub>	1927	***
$\beta_7$	YR <sub>1</sub>	-3512	***
$\beta_8$	YR <sub>2</sub>	-640	***
$\beta_9$	YR <sub>3</sub>	-1673	***
$\beta_{10}$	YR <sub>4</sub>	-972	***
$\beta_{11}$	LOC	-931	***

\*\*, \*\*\* Statistically significant at  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

<sup>a</sup> Only those coefficients significant at the 5% level are shown; intercept for simultaneous regression with seven components was 709 kg ha<sup>-1</sup>.

### 5.1.3 Conclusions

Crop management practices differed in their impact on soil PR. While stubble management and cropping sequence had minimal effect on soil penetrometer resistance (PR), tillage exerted a major effect, particularly in the surface layer (0-15 cm) of the soil. Conservation tillage practices, both in mechanized and ox-plow tillage systems, significantly increased soil PR vis-à-vis conventional tillage. Measured soil PR values were significantly associated with wheat grain yield in the current study. However, PR at the 0-5 cm depth was negatively related to grain yield, while PR at the 20-25 cm depth was positively related to grain yield.

## 5.2 Effects on soil chemical properties

### 5.2.1 Introduction

Soil chemical properties can have a critical impact on crop production. In order to attain crop production goals, it is important to maintain an optimal soil environment. Integrated crop management practices may be the most effective means of achieving this goal. Crop residue maintenance, reduced or conservation tillage, and crop rotation are among the crop management practices that can play a significant role in optimising soil chemical properties (Aulakh & Gill, 1988; Stobbe, 1990; Sweeney & Moyer, 1995). Conservation tillage practices generally retain most of the residue from previous crops on the soil surface by minimising mechanical manipulation and mixing of the soil. Reduced soil mixing combined with the retention of crop residues on the surface can markedly change soil chemical properties through the soil profile over time (Blevins *et al.*, 1983b; Griffith *et al.*, 1988).

Retention of crop residues on the soil surface may help to conserve soil organic matter and water, especially when coupled with conservation tillage (Griffith *et al.*, 1986). In addition, retention of crop residue on the soil surface has been shown to increase total nitrogen (N) in the top 15 cm of soil (Rasmussen & Collins, 1991). These authors attributed the higher level of N in the surface soil layer to a slower rate of residue decomposition. Straw orientation may be an important factor as decomposition is hastened when the straw is flattened and placed in contact with the soil (Bulman & Stobbe, 1994).

Stubble burning is controversial, and its demerits are considered to outweigh its merits due to undesirable changes in soil chemical properties over the long-term (Rasmussen & Rohde, 1988). However, stubble burning can result in a short-term yield advantage by reducing the incidence of root diseases and the density of weed seeds in the soil (Rasmussen *et al.*, 1986).

Tillage practices can affect various soil chemical properties, including organic matter (OM), nitrate ( $\text{NO}_3$ ), and ammonium ( $\text{NH}_4$ ) content. As the degree of tillage disturbance increases, deterioration of soil structure and increased erosion become more pronounced. Conservation tillage practices can reduce such deleterious soil effects (Stobbe, 1990). Reduced tillage can increase the water and OM content in the surface layer of the soil, and

enhance water infiltration (Kamwaga, 1990). This author indicated that 50% straw retention increased soil water content. However, others have reported that conventional tillage increased rainfall infiltration, soil aeration and soil temperature under specific environmental and edaphic conditions (Throckmorton, 1986).

Soil chemical properties can be modified by specific cropping systems. Several long-term studies have demonstrated the beneficial effects of crop rotation, especially with the inclusion of legumes (Odell *et al.*, 1984; Johnston, 1986). These studies generally revealed that crop rotations including legumes, increased soil organic C and N after several years of cropping even without manure or fertiliser N input, and contrasted markedly with continuous cereal sequences. The contribution of legumes to soil OM, NO<sub>3</sub> and NH<sub>4</sub> content has considerable practical significance for small-scale agriculture in Africa.

In Ethiopia, changes in chemical soil properties have not been studied in relation to the long-term effects of stubble management, tillage practice and cropping sequence. Thus, this study was initiated to examine the effects of integrated crop management systems on soil chemical properties in the south-eastern highlands of Ethiopia.

## 5.2.2 Results and Discussion

The results of the combined ANOVA across years for the measured pre-plant soil chemical properties at both locations of the mechanised and ox-plow trials are presented in Tables 5.7 to 5.10. The results revealed that year, depth, and year by depth effects comprised a high proportion of total variability, reflecting a pronounced environmental effect on soil chemical properties.

### 5.2.2.1 Soil pH

Analysis of the effect of straw management on soil pH revealed a significant effect in the Kulumsa mechanised trial during 1999 (Appendix 5.1), in the Asasa mechanised trial during 1998 (Appendix 5.3), and in the Kulumsa ox-plow trial during 1996 (Appendix 5.5). In the Kulumsa mechanised trial, BURN significantly increased soil pH cf. RET,

**Table 5.7. Effect of crop management practices on pre-planting soil chemical properties in the mechanised system trial at Kulumsa: ANOVA results combined across years.**

	NO <sub>3</sub> (mg kg <sup>-1</sup> )	NH <sub>4</sub> (mg kg <sup>-1</sup> )	pH (1:1 H <sub>2</sub> O)	P (mg kg <sup>-1</sup> )	K (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )
Year (Y)	*	***	**	**	**	**
SM		†			†	
SM x Y						***
Tillage (T)						
T x Y						
SM x T		*			†	
SM x T x Y		**				
CS						
CS x Y						
SM x CS						
SM x CS x Y				**		
T x CS					**	
T x CS x Y					†	
SM x T x CS						
SM x T x CS x Y				*		
Depth (D)			*	†	†	
D x Y	**	***	***	***	**	***
SM x D				†	**	**
SM x D x Y		**				
T x D				*	*	
T x D x Y						
SM x T x D						†
SM x T x D x Y					*	
CS x D		*	*			**
CS x D x Y						
SM x CS x D						
SM x CS x D x Y						
T x CS x D						
T x CS x D x Y						
SM x T x CS x D						
SM x T x CS x D x Y						
Mean	20.0	13.1	5.9	12.8	541	0.43
C.V.(%)	23.3	18.9	3.95	29.4	8.70	22.2

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

SM= Straw management; CS = Cropping sequence.

**Table 5.8. Effect of crop management practices on pre-planting soil chemical properties in the mechanised system trial at Asasa: ANOVA results combined across years.**

	NO <sub>3</sub> (mg kg <sup>-1</sup> )	NH <sub>4</sub> (mg kg <sup>-1</sup> )	pH (1:1 H <sub>2</sub> O)	P (mg kg <sup>-1</sup> )	K (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )
Year (Y)	**	*		***	*	
SM						***
SM x Y						
Tillage (T)						
T x Y	*					
SM x T		†				
SM x T x Y			†			
CS						
CS x Y			†			†
SM x CS						
SM x CS x Y				†		
T x CS	†					
T x CS x Y						
SM x T x CS				*		†
SM x T x CS x Y						
Depth (D)			***	***	†	***
D x Y	***		***	***	†	
SM x D				**		*
SM x D x Y						
T x D	**			**		
T x D x Y						
SM x T x D	†					
SM x T x D x Y			*			
CS x D					*	
CS x D x Y						
SM x CS x D				*		
SM x CS x D x Y				†		
T x CS x D				†		
T x CS x D x Y		†				
SM x T x CS x D						
SM x T x CS x D x Y						
Mean	22.5	11.2	5.9	22.4	576	0.82
C.V.(%)	33.0	31.4	4.51	20.1	18.4	26.4

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

SM= Straw management; CS = Cropping sequence.

**Table 5.9. Effect of crop management practices on pre-planting soil chemical properties in the ox-plow system trial at Kulumsa: ANOVA results combined across years.**

	NO <sub>3</sub> (mg kg <sup>-1</sup> )	NH <sub>4</sub> (mg kg <sup>-1</sup> )	pH (1:1 H <sub>2</sub> O)	P (mg kg <sup>-1</sup> )	K (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )
Year (Y)	***	†	***	***	**	*
SM						
SM x Y		†			†	
Tillage (T)						
T x Y		*		†		
SM x T			**		†	†
SM x T x Y						
CS						
CS x Y		*				
SM x CS					†	
SM x CS x Y						
T x CS						
T x CS x Y						†
SM x T x CS	*					
SM x T x CS x Y						*
Depth (D)				*	***	
D x Y	***	***	***	***		***
SM x D						
SM x D x Y					*	
T x D		**			**	**
T x D x Y		*				
SM x T x D						
SM x T x D x Y						
CS x D				†	†	
CS x D x Y						
SM x CS x D	*	*				
SM x CS x D x Y	*					
T x CS x D	*				**	
T x CS x D x Y						
SM x T x CS x D	*					*
SM x T x CS x D x Y	†	†				
Mean	21.9	12.0	6.0	11.9	516	0.63
C.V.(%)	21.6	17.6	5.32	18.8	11.9	21.4

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

SM= Straw management; CS = Cropping sequence.

Table 5.10. Effect of crop management practices on pre-planting soil chemical properties in the ox-plov system trial at Asasa: ANOVA results combined across years.

	NO <sub>3</sub> (mg kg <sup>-1</sup> )	NH <sub>4</sub> (mg kg <sup>-1</sup> )	pH (1:1 H <sub>2</sub> O)	P (mg kg <sup>-1</sup> )	K (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )
Year (Y)		**	*	***	†	†
SM				*		
SM x Y						
Tillage (T)			***			
T x Y						
SM x T						
SM x T x Y		**				
CS						
CS x Y			*			
SM x CS			†			
SM x CS x Y				†		
T x CS						*
T x CS x Y	†			†		
SM x T x CS						
SM x T x CS x Y						***
Depth (D)			*	***		†
D x Y	***	**	***	***	***	***
SM x D						
SM x D x Y					*	
T x D			†		†	
T x D x Y						
SM x T x D						
SM x T x D x Y						
CS x D						
CS x D x Y						
SM x CS x D						
SM x CS x D x Y						
T x CS x D						
T x CS x D x Y						
SM x T x CS x D						
SM x T x CS x D x Y		†		*		
Mean	22.1	10.1	6.0	19.6	478	0.72
C.V.(%)	20.8	26.2	5.03	19.2	15.8	30.4

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

SM= Straw management; CS = Cropping sequence.

while PARM was intermediate and equal to the other two treatments (Appendix 5.2). In the Asasa mechanised trial, RET markedly increased soil pH cf. BURN, while PARM was

again intermediate and equal to the other two SM treatments (Appendix 5.4). In the Kulumsa ox-plow trial, PARM exhibited an increased soil pH cf. BURN (Appendix 5.6). In general, the effect of SM on soil pH was non-significant for the majority of the site-season combinations. It was apparent that pH consistently increased with soil depth.

Tillage showed a significant effect on soil pH only in the Asasa mechanised trial during 1999, in which case MT exhibited an increased soil pH relative to CT (Appendix 5.4). CS significantly affected soil pH in the Kulumsa ox-plow trial during 1996 and 1999 (Appendix 5.5). In each case, CW exhibited a higher soil pH cf. the faba bean rotation (Appendix 5.6). This might be the consequence of a higher soil N content due to N fixation by the faba bean precursor, resulting in a lower soil pH. In this trial, CS showed a consistent effect on soil pH. No interaction effects were observed for soil pH across the individual trials and seasons.

In the combined analysis across years tillage significantly affected soil pH in the Asasa ox-plow trial (Table 5.11). The soil pH was higher under conventional tillage cf. MT. Blevins *et al.* (1977) reported that soil pH was significantly lower under no-tillage as compared to conventional tillage in the upper 5 cm soil layer.

**Table 5.11. Effect of tillage practices on pre-planting soil pH in the ox-plow system trial at Asasa: treatment means.**

Tillage	pH (1:1 H <sub>2</sub> O)
Conventional	6.10A
Minimum	5.91B

Values followed by the same letter within a column are not significantly different at the 5% level of the LSD test.

The interaction of SM by tillage exhibited a significant effect on soil pH in the Kulumsa ox-plow trial (Table 5.14). CT with BURN and MT with PARM increased the soil pH cf. the other two SM by tillage combinations. It has been reported that soil OM accumulation under no-tillage management alleviates problems associated with lower soil pH (Hargrove & Thomas, 1981).

The interaction between year and CS revealed a significant effect on soil pH in the Asasa mechanised trial during 1999 and in the Asasa ox-plow trial during 1996 and 1998 (Table 5.15). In two these instances, CW significantly increased soil pH cf. the faba bean rotation, while in the Asasa ox-plow trial during 1998 the faba bean rotation increased soil pH.

A significant interaction of SM by CS was observed in the Asasa ox-plow trial (Table 5.16). For the faba bean rotation combined with partial removal of stubble resulted in a lower pH cf. the other three SM by CS combinations.

The interaction of tillage by depth exhibited a significant effect on pH in the Asasa ox-plow trial (Table 5.19). CT exhibited a higher soil pH than MT at the 15-30 and 30-60 cm depths.

A significant interaction between CS and depth was observed in the Kulumsa mechanised trial (Table 5.20). The faba bean rotation resulted in a lower soil pH at the 0-15 and 15-30 cm depths cf. the CW treatment.

#### 5.2.2.2 Soil nitrate

Soil  $\text{NO}_3$  decreased with soil depth for all site-season combinations, except the mechanised and ox-plow trials at Kulumsa during 1996 (Appendix 5.2 and 5.6). This discrepancy was probably due to the occurrence of heavy rainfall at Kulumsa during the early part of the cropping cycle in 1996.

Tillage significantly affected soil  $\text{NO}_3$  in the Asasa mechanised trial during 1998 (Appendix 5.3). CT significantly increased soil  $\text{NO}_3$  cf. MT (Appendix 5.4). Dowdall *et al.* (1983) also reported higher nitrate concentrations in plowed fields than in directly drilled plots. It is perhaps not surprising that soil disturbance by plowing increases nitrate concentration in the soil, presumably due to an increased rate of organic matter mineralisation.

CS showed a significant effect on soil  $\text{NO}_3$  in the Kulumsa mechanised trial during 1996 (Appendix 5.1). The faba bean rotation increased soil  $\text{NO}_3$  cf. CW (Appendix 5.2). The inclusion of a grain legume in the cropping sequence generally increases soil nitrate as compared to continuous wheat (Wacquant *et al.*, 1989).

The interaction between tillage and depth was significant in the Asasa mechanised trial during 1998 (Appendix 5.3). Conventional tillage exhibited a higher level of soil  $\text{NO}_3$  than MT, but only in the 0-15 cm soil depth (Appendix 5.11). Under conventional tillage, the soil in the plow layer is inverted each year resulting in a fairly uniform distribution of organic matter in the top 0.2 m of soil (Haynes & Knight, 1989).

From the combined ANOVA, a significant interaction between year and tillage was observed for the mechanised trial at Asasa (Table 5.8). MT exhibited a lower soil nitrate level cf. CT, but only during the 1998 season (Table 5.13).

The interaction between tillage and depth significantly affected soil  $\text{NO}_3$  in the Asasa mechanised trial (Table 5.8). CT increased soil  $\text{NO}_3$  cf. MT, but only in the 0-15 cm soil depth (Table 5.19). Kitur *et al.* (1984) evaluated the influence of no-tillage and mouldboard plowing on crop recovery and transformation of fertiliser N; with mouldboard tillage, fertiliser N was more uniformly distributed throughout the surface 15 cm soil layer which is equivalent to the depth of plowing.

The interaction between year and depth revealed significant differences in soil  $\text{NO}_3$  in the soil profile in the Kulumsa mechanised trial during 1997 and 1998, in the Asasa mechanised trial during 1996, 1997 and 1998, in the Kulumsa ox-plow system trial during 1997 and 1998, and in the Asasa ox-plow trial during 1996, 1997 and 1998 (Tables 5.21 to 5.24). For most site-season combinations, the  $\text{NO}_3$  content of the soil decreased with depth.

### 5.2.2.3 Soil ammonium

Soil  $\text{NH}_4$  tended to decrease with soil depth for all site-season combinations except the Kulumsa mechanised and ox-plow trials during 1996 (Appendices 5.1 to 5.8).

Tillage significantly affected soil  $\text{NH}_4$  in the Kulumsa mechanised and Asasa ox-plow trials during 1996 (Appendix 5.1 and 5.5). In the Kulumsa trial, CT markedly increased soil  $\text{NH}_4$  cf. MT (Appendix 5.2). With CT, the soil in the plowed layer is inverted annually so that there is a fairly uniform distribution of available organic N within the top 20 cm (Khakural *et al.*, 1992). In contrast, MT significantly increased the  $\text{NH}_4$  concentration of the soil in the Asasa ox-plow trial as compared to CT (Appendix 5.8). Conservation tillage retains most of the crop residue on the soil surface by minimising mechanical manipulation, resulting in changes to soil chemical properties over time (Blevins *et al.*, 1983a).

CS significantly affected soil  $\text{NH}_4$  only in the Kulumsa ox-plow trial during 1996 (Appendix 5.5). CW exhibited increased soil  $\text{NH}_4$  cf. the faba bean rotation (Appendix 5.6).

The interaction between SM and depth was significant for soil  $\text{NH}_4$  in the Kulumsa mechanised trial during 1996 (Appendix 5.1). Soil  $\text{NH}_4$  levels were only different among SM treatments at the 30-60 cm depth. At this depth, PARM or RET exhibited an increased soil  $\text{NH}_4$ , while the BURN treatment resulted in the lowest soil  $\text{NH}_4$  level (Appendix 5.9).

The interaction between tillage and depth was significant for soil  $\text{NH}_4$  concentration in the Kulumsa mechanised trial during 1998 (Appendix 5.1). CT resulted in a higher soil  $\text{NH}_4$  level than ZT, but only at the 15-30 cm depth (Appendix 5.11).

In the combined analysis, SM significantly affected soil  $\text{NH}_4$  in the Kulumsa mechanised trial (Table 5.7). RET and PARM resulted in higher levels of soil  $\text{NH}_4$  in contrast with BURN (Table 5.12). Rasmussen & Collins (1991) stated that retaining crop residues on the soil surface rather than burning or incorporating them by tillage, increased organic C and total N in the top 15 cm of the soil.

The interaction between tillage and year was significant for soil  $\text{NH}_4$  in the ox-plow trial at Kulumsa (Table 5.9). Only during 1998, CT increased soil  $\text{NH}_4$  as compared to MT (Table

5.13). Under CT, soil fertiliser N was more uniformly distributed throughout the plow surface layer and mineralisation and transformation of fertiliser N was increased (Kitur *et al.*, 1984).

A significant interaction between SM and tillage was observed for soil  $\text{NH}_4$  in the Kulumsa mechanised trial (Table 5.7). BURN in combination with ZT markedly decreased soil  $\text{NH}_4$  relative to the other treatment combinations; in general, RET and PARM, with either tillage treatment, exhibited equal  $\text{NH}_4$  levels (Table 5.14).

The interaction between year and CS was significant for soil  $\text{NH}_4$  in the Kulumsa ox-plow trial (Table 5.9). Only during the 1998 season, the faba bean rotation exhibited an increased level of  $\text{NH}_4$  as compared to the CW treatment. Many studies have indicated that cultivation of  $\text{N}_2$  fixing legumes increases soil N content (Senaraine & Hardarson, 1988).

**Table 5.12. Effect of straw management practice on pre-planting soil chemical properties in the mechanised and ox-plow system trials at Kulumsa and Asasa: treatment means.**

Straw management	Kulumsa mechanised		Asasa mechanised	Asasa ox-plow
	$\text{NH}_4$ ( $\text{mg kg}^{-1}$ )	K ( $\text{mg kg}^{-1}$ )	Zn ( $\text{mg kg}^{-1}$ )	P ( $\text{mg kg}^{-1}$ )
Burn	12.2B	536B	0.89A	20.3A
Removal	13.8A	516C	0.97A	18.9B
Retention	13.3A	573A	0.75B	---
LSD(5%)	0.97	17.9	0.14	---

Values followed by the same letter within a column are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

The interaction between tillage and depth was significant for soil  $\text{NH}_4$  in the Kulumsa ox-plow trial (Table 5.9). CT significantly increased soil  $\text{NH}_4$  cf. MT, but only for the 0-15 cm soil depth.

The interaction between year and depth revealed significant differences in soil  $\text{NH}_4$  in the soil profile in the Kulumsa mechanised trial during 1996 and 1998, in the Asasa mechanised trial during 1996, 1997 and 1998, in the Kulumsa ox-plow trial during 1996 and 1998, and in the Asasa ox-plow trial during 1998 (Tables 5.21 to 5.24). With the

exception of the Kulumsa mechanised and ox-plow trials during 1996, soil  $\text{NH}_4$  decreased with soil depth in all other site-season combinations.

#### 5.2.2.4 Soil phosphorus

In general, soil phosphorus decreased with soil depth because P is a less mobile plant nutrient in the soil profile (Appendices 5.1 to 5.8).

Tillage significantly affected soil P in the Asasa ox-plow trial during 1998 (Appendix 5.7). For this site-season combination, MT exhibited a higher level of soil P cf. conventional tillage (Appendix 5.8).

CS significantly affected soil P in the Asasa mechanised trial during 1999 (Appendix 5.3). CW exhibited a significantly higher level of soil P (Appendix 5.4).

**Table 5.13. Effect of interaction of year by tillage on pre-planting soil chemical properties in the mechanised and ox-plow system trials at Kulumsa and Asasa.**

Year	Asasa mechanised		Kulumsa ox-plow			
	$\text{NO}_3$ ( $\text{mg kg}^{-1}$ )		$\text{NH}_4$ ( $\text{mg kg}^{-1}$ )		P ( $\text{mg kg}^{-1}$ )	
	CT	MT	CT	MT	CT	MT
1996	22.3	21.0	10.0	10.3	23.8	23.5
1997	25.1	25.8	11.7	12.2	14.2A	13.1B
1998	23.9A	16.6B	15.0A	12.6B	5.4B	6.5A
1999	---	---	---	---	4.5	4.6
LSD(5%)	4.21		1.69		0.84	

Values followed by the same or no letter within a row are not significantly different at the 5% level of the LSD test.

CT = Conventional tillage; MT = Minimum tillage.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

The interaction between SM and depth exhibited a significant effect on soil P in the Kulumsa mechanised trial during 1999 (Appendix 5.9) and in the Asasa mechanised trial during 1997 (Appendix 5.10). In the Kulumsa mechanised trial, BURN resulted in a higher soil P level than the other SM treatments, but only in the surface layer. In the Asasa trial, PARM increased soil P in the 0-15 cm layer. Several studies have attributed such a stratification of P to its slow movement into the soil profile (Eckert & Johnson, 1985).

The interaction between tillage and depth was significant for soil P in the Asasa mechanised trial during 1997 and 1999 (Appendix 5.11). In both seasons, soil P content tended to be higher under MT in the 0-15 cm soil layer, while P levels were lower under MT in the two deeper soil layers. Many studies have shown that no-tillage systems tend to accumulate P near the soil surface and with decreasing P levels deeper in the soil profile. This often results in higher soil test P levels at the soil surface than when the soil is periodically inverted by tillage (Cruse *et al.*, 1983; Fink & Wesley, 1974; Triplett & van Doren, 1969).

In the combined analysis over years, SM significantly affected soil P content in the Asasa ox-plow trial (Table 5.10). The BURN treatment significantly increased soil P cf. PARM (Table 5.12).

The interaction between year and tillage revealed significant differences in soil P content in the Kulumsa ox-plow trial during 1997 and 1998 (Table 5.13). In 1997, CT increased soil P content, while, in 1998, MT significantly increased soil P content.

The interaction between SM and depth significantly affected soil P content in the mechanised trials at Kulumsa and Asasa (Table 5.18). In the Kulumsa mechanised trial, PARM > BURN = RET in the 0-15 cm layer, while PARM > BURN and RET was equal to the other two treatments in the 15-30 cm layer. In the Asasa mechanised trial, the same trend was observed as for the Kulumsa mechanised trial in the 0-15 cm layer, but, for the 15-30 cm layer, BURN > RET while PARM was intermediate and equal to the other two SM treatments (Table 5.18).

The interaction between tillage and depth was significant for soil P in the mechanised trials at Kulumsa and Asasa (Table 5.19). At each site, the interaction effect followed the same pattern where CT markedly increased soil P cf. ZT/MT in the 0-15 and 30-60 cm depths, while, in the 15-30 cm layer, CT < ZT/MT (Table 5.19).

The interaction between CS and depth was significant for soil P in the Kulumsa ox-plow trial (Table 5.20). CW increased the soil P level relative to the faba bean rotation, but only in the upper layer of the soil (0-15 cm). This might be due to the high demand for P by faba bean for growth and development during the break crop year or the high demand of wheat following the faba bean precursor due to enhanced vegetative growth.

The interaction between year and depth revealed significant differences for P levels in the soil profile in the Kulumsa mechanised trial during 1996, 1998 and 1999, in the Asasa mechanised trial during 1996, 1997, 1998 and 1999, in the Kulumsa ox-plow trial during 1996, 1997 and 1999, and in the Asasa ox-plow trial during 1996, 1997, 1998 and 1999 (Tables 5.21 to 5.24). In each site-season combination, the P content of the soil decreased with soil depth.

#### **5.2.2.5 Soil potassium**

In general, soil K decreased with soil depth, with the exception of the Asasa ox-plow trial during 1999 (Appendices 5.1 to 5.8).

SM significantly affected soil K content in the Kulumsa mechanised trial during 1998 and 1999 (Appendix 5.1). In 1998, RET > BURN > PARM, while, in 1999, RET > PARM and BURN was intermediate and equal to the other two treatments (Appendix 5.2).

CS affected soil K content significantly in the Asasa mechanised trial during 1999 and in the Kulumsa ox-plow trial during 1998 (Appendices 5.3 and 5.5). In both cases, the CW treatment exhibited a significant increase in soil K content (Appendices 5.4 and 5.6). Thus, CS showed a consistent effect on soil K content in both trials.

The interaction between SM and depth was significant for soil K in the Kulumsa mechanised trial during 1998 and 1999 (Appendix 5.9), and in the ox-plow trials at Kulumsa and Asasa during 1999 (Appendix 5.13). In the mechanised trial at Kulumsa in both years, RET significantly increased the K content in the upper soil layer (0-15 cm),

while RET was higher than PARM in the 15-30 cm layer. In the two ox-plow trials, BURN increased soil K content cf. PARM, but only in the surface layer.

The interaction between tillage and depth was significant for soil K in the Kulumsa and Asasa mechanised trials during 1999 (Appendix 5.11). In the Kulumsa trial, CT significantly increased soil K in the first two soil depths (i.e., 0-15 and 15-30) cf. ZT. In the Asasa trial, the soil K level appeared to be higher under MT in the 0-15 cm layer and under CT in the 15-30 cm layer.

The interaction between CS and depth was significant for soil K in the Asasa mechanised trial during 1999 (Appendix 5.12). CW increased soil K cf. the faba bean rotation, but only in the 0-15 cm soil depth.

In the combined analysis across years, SM significantly affected soil K in the Kulumsa mechanised trial (Table 5.12). RET increased soil K cf. BURN, while PARM exhibited the lowest K content of the three treatments (Table 5.12). Blevins *et al.* (1977) noted that under stubble retention potassium tended to be more concentrated in the first few cm of the soil profile.

The interaction between SM and tillage significantly affected soil K in the Kulumsa mechanised trial (Table 5.14). RET with ZT increased soil K relative to the other treatment combinations. For the BURN and PARM SM treatments, there was no effect of tillage treatment. Triplett & van Doren (1969) found that soil K levels in the surface 5 cm were greater under a no-tillage treatment.

The interaction between SM and CS significantly affected soil K in the ox-plow trial at Kulumsa (Table 5.16). Partial removal of crop stubble in combination with continuous wheat significantly increased the soil K content relative to the combination of PARM with the faba bean rotation.

**Table 5.14. Effect of interaction of straw management by tillage on pre-planting soil chemical properties pre-planting in the mechanised and ox-pow system trials at Kulumsa and Asasa.**

Straw management	Kulumsa mechanised				Asasa mechanised		Kulumsa ox-pow	
	NH <sub>4</sub> (mg kg <sup>-1</sup> )		K (mg kg <sup>-1</sup> )		NH <sub>4</sub> (mg kg <sup>-1</sup> )		pH (1:1 H <sub>2</sub> O)	
	CT	ZT	CT	ZT	CT	MT	CT	MT
Burn	12.9B	11.4C	558AB	514B	11.9A	10.8AB	6.0A	5.9B
Remove	13.6AB	14.0A	514B	517B	11.2AB	12.1A	5.9B	6.0A
Retention	13.3AB	13.3AB	543B	602A	10.5B	10.5B	---	---
LSD(5%)	0.95		54.5		1.37		0.099	

Values followed by the same letters for each parameter are not significantly different at the 5% level of the LSD test.

CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage.

**Table 5.15. Effect of interaction of year by cropping sequence on pre-planting soil chemical properties in the mechanised and ox-pow system trials at Kulumsa and Asasa.**

Cropping Sequence	Asasa mechanised						Kulumsa ox-pow			Asasa ox-pow			
	pH (1:1 H <sub>2</sub> O)				Zn (mg kg <sup>-1</sup> )		NH <sub>4</sub> (mg kg <sup>-1</sup> )			pH (1:1 H <sub>2</sub> O)			
	1996	1997	1998	1999	1998	1999	1996	1997	1998	1996	1997	1998	1999
Faba bean	5.77	5.64	5.91	6.00B	0.93A	0.80	9.78	11.9	14.4A	6.04B	5.71	5.98A	5.98
Wheat	5.81	5.61	6.00	6.21A	0.80B	0.87	10.5	11.8	13.1B	6.15A	5.67	5.62B	6.04
LSD(5%)	0.13				0.12		1.04			0.08			

Values followed by the same or no letter within each column are not significantly different at the 5% level of the LSD test.

The interaction between tillage and CS significantly affected soil K content (Table 5.17): ZT in combination with CW increased the soil K content relative to the other three treatment combinations.

**Table 5.16. Effect of interaction of straw management by cropping sequence on pre-planting soil chemical properties in the ox-plow system trials at Kulumsa and Asasa**

Straw management	Kulumsa ox-plow		Asasa Ox-plow	
	K (mg kg <sup>-1</sup> )		pH (1:1 H <sub>2</sub> O)	
	FB	CW	FB	CW
Burn	514AB	520AB	5.98A	5.98A
Remove	494B	537A	5.88B	6.01A
LSD(5%)	27.3		0.095	

Values followed by the same letter for each parameter are not significantly different at the 5% level of the LSD test.

FB = Faba bean rotation with wheat (1 year in 3); CW = Continuous wheat.

**Table 5.17. Effect of interaction of tillage by cropping sequence on pre-planting soil chemical properties in the mechanised and ox-plow system trials at Kulumsa and Asasa**

Cropping sequence	Kulumsa mechanised		Asasa ox-plow	
	K (mg kg <sup>-1</sup> )		Zn (mg kg <sup>-1</sup> )	
	CT	ZT	CT	MT
FB	541B	523B	0.77A	0.69C
CW	535B	565A	0.70BC	0.74AB
LSD(5%)	23.4		0.047	

Values followed by the same letter for each parameter are not significantly different at the 5% level of the LSD test.

CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage; FB = Faba bean rotation with wheat (1 year in 3); CW = continuous wheat.

The interaction between SM and depth was significant for soil K in the Kulumsa mechanised trial (Table 5.18). RET resulted in the highest soil K level in the two uppermost soil layers. In both layers, BURN was lower than RET, and PARM was lower than BURN. Various studies have shown that the reduction in soil cultivation associated with minimum or zero tillage can significantly change the distribution of plant available nutrients in the soil profile (Blevins *et al.*, 1977; Drew & Saker, 1980). Such changes are

characterised by concentration gradients in the soil profile for the less mobile plant nutrients (e.g., phosphorus and potassium) under reduced tillage.

The interaction between tillage and depth revealed significant differences in soil K content in the soil profile in the Kulumsa mechanised and ox-plow trials and in the Asasa ox-plow trial (Table 5.19). In the Asasa ox-plow trial, MT significantly increased soil K at the 0-15 cm depth. Kulumsa ox-plow trial, CT increased soil K at 0-15 cm and decreased soil K content at 15-30 cm. In the Kulumsa mechanised trial, only the 30-60 cm soil layer exhibited a difference in soil K content. In this instance, ZT exhibited a higher level of soil K cf. CT. Thus, the effects of the tillage by depth interaction were highly variable across the trial sites.

The interaction between CS and depth revealed significant differences in soil K in the soil profile in the Asasa mechanised trial and in the Kulumsa ox-plow trial (Table 5.20). For both trials, CW significantly increased soil K cf. the faba bean rotation, but only for the 0-15 cm soil depth.

The interaction between year and depth revealed significant differences in soil K content in the soil profile in the mechanised trials at Kulumsa and Asasa and the ox-plow trial at Asasa during 1998 and 1999 (Tables 5.21, 5.22 and 5.24). Soil K tended to decrease with soil depth, with the exception of the Asasa trials which showed an increase for the bottom layer relative to the middle soil layer (Table 5.24).

#### **5.2.2.6 Soil zinc**

For each sampled trial and season combination, Zn content decreased with soil depth (Appendices 5.1 to 5.8). SM significantly affected soil Zn in the Kulumsa mechanised trial where RET increased soil Zn cf. PARM and BURN (Appendix 5.2).

The interaction between SM and depth was significant for soil Zn in the Kulumsa mechanised trial during 1998 and 1999 (Appendix 5.9), and in the Asasa mechanised trial

**Table 5.18. Effect of interaction of straw management by depth on pre-planting soil chemical properties in the mechanised system trial at Kulumsa and Asasa.**

Depth (cm)	Kulumsa mechanised									Asasa mechanised					
	P (mg kg <sup>-1</sup> )			K (mg kg <sup>-1</sup> )			Zn (mg kg <sup>-1</sup> )			P (mg kg <sup>-1</sup> )			Zn (mg kg <sup>-1</sup> )		
	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain
0-15	15.2B	17.5A	14.0BC	598B	566C	657A	0.59B	0.62AB	0.67A	28.0B	31.9A	28.6B	1.25B	1.38A	1.18BC
15-30	11.0EF	13.1CD	12.3DE	519D	486E	550C	0.36D	0.41D	0.51C	21.4C	20.9CD	19.3DE	0.99D	1.14C	0.78E
30-60	10.4F	11.6DEF	10.1F	491E	495DE	511DE	0.24E	0.21E	0.23E	18.0EF	17.0F	16.4F	0.43F	0.37F	0.28G
LSD(5%)	1.52			27.0			0.054			1.81			0.087		

Values followed by the same letter within a parameter are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

**Table 5.19. Effect of interaction of tillage by depth on pre-planting soil chemical properties in the mechanised and ox-plover system trials at Kulumsa and Asasa.**

Depth (cm)	Kulumsa mechanised				Asasa mechanised				Kulumsa ox-plover				Asasa ox-plover					
	P (mg kg <sup>-1</sup> )		K (mg kg <sup>-1</sup> )		NO <sub>3</sub> (mg kg <sup>-1</sup> )		P (mg kg <sup>-1</sup> )		NH <sub>4</sub> (mg kg <sup>-1</sup> )		K (mg kg <sup>-1</sup> )		Zn (mg kg <sup>-1</sup> )		pH (1:1 H <sub>2</sub> O)		K (mg kg <sup>-1</sup> )	
	CT	ZT	CT	ZT	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT
0-15	14.5B	12.1C	615A	599A	31.5A	25.2B	28.8A	21.6B	13.1A	11.6B	616A	564B	0.95A	0.86B	5.70D	5.71D	474B	525A
15-30	10.6D	16.6A	516B	520B	23.9B	22.7B	17.7D	30.1A	12.6A	12.2AB	486C	494C	0.60D	0.70C	5.99C	5.82D	405C	430C
30-60	12.2C	10.8D	484C	514B	15.8C	15.4C	19.4C	16.6D	11.0C	11.4BC	447D	488C	0.35E	0.33E	6.35A	6.20B	526A	509AB
LSD(5%)	1.24		22.0		2.82		1.48		0.98		35.5		0.077		0.12		43.1	

Values followed by the same letters within a parameter are not significantly different at the 5% level of the LSD test.

CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

**Table 5.20. Effect of interaction of cropping sequence by depth on pre-planting soil chemical properties in the mechanised and ox-plov system trials at Kulumsa and Asasa**

Depth (cm)	Kulumsa mechanised						Asasa mechanised		Kulumsa ox-plov			
	NH <sub>4</sub> (mg kg <sup>-1</sup> )		pH (1:1 H <sub>2</sub> O)		Zn (mg kg <sup>-1</sup> )		K (mg kg <sup>-1</sup> )		P (mg kg <sup>-1</sup> )		K (mg kg <sup>-1</sup> )	
	FB	CW	FB	CW	FB	CW	FB	CW	FB	CW	FB	CW
0-15	13.3AB	13.9A	5.76D	5.85C	0.60B	0.65A	641B	707A	14.5B	15.7A	563B	617A
15-30	12.1C	12.9BC	5.92C	6.02B	0.45C	0.40D	482D	518CD	10.9C	11.4C	479CD	502C
30-60	13.1AB	13.1AB	6.21A	6.17A	0.25E	0.20F	564C	544C	9.7D	9.4D	470CD	466D
LSD(5%)	0.94		0.078		0.044		49.3		0.85		35.4	

Values followed by the same letter within a parameter are not significantly different at the 5% level of the LSD test.

FB = Faba bean rotation with wheat (1 year in 3); CW = continuous wheat.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

**Table 5.21. Effect of interaction of year by depth on pre-planting soil chemical properties in the mechanised system trial at Kulumsa**

Depth (cm)	NO <sub>3</sub> (mg kg <sup>-1</sup> )			NH <sub>4</sub> (mg kg <sup>-1</sup> )			pH (1:1 H <sub>2</sub> O)				P (mg kg <sup>-1</sup> )				K (mg kg <sup>-1</sup> )		Zn (mg kg <sup>-1</sup> )	
	1996	1997	1998	1996	1997	1998	1996	1997	1998	1999	1996	1997	1998	1999	1998	1999	1998	1999
0-15	17.8	29.5A	21.7A	16.2B	10.8	12.4A	6.13	5.44B	5.84C	5.82C	25.6A	16.6	13.3A	6.8A	813A	400A	0.34A	0.91A
15-30	18.8	28.9B	11.2B	18.4A	10.2	11.9A	6.13	5.45B	6.21B	6.07B	23.2B	16.2	6.4B	2.6B	699B	328B	0.22B	0.63B
30-60	19.7	26.9B	6.1C	17.8A	10.2	9.9B	6.23	5.61A	6.60A	6.34A	23.5B	16.3	2.0C	1.0B	684B	314B	0.16C	0.29C
LSD(5%)	2.17			1.15			0.11				1.75				22.0		0.030	

Values followed by the same or no letter within a column for each parameter are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Table 5.22. Effect of interaction of year by depth on pre-planting soil chemical properties in the mechanised system trial at Asasa

Depth (cm)	NO <sub>3</sub> (mg kg <sup>-1</sup> )			pH (1:1 H <sub>2</sub> O)				P (mg kg <sup>-1</sup> )				K (mg kg <sup>-1</sup> )	
	1996	1997	1998	1996	1997	1998	1999	1996	1997	1998	1999	1998	1999
0-15	23.4A	28.9A	32.8A	5.64C	5.50B	5.58C	5.76C	41.5A	37.0A	21.6A	17.8A	853A	495A
15-30	23.1A	27.0A	19.9B	5.77B	5.60B	5.80B	6.08B	36.3B	28.3B	9.4B	8.1B	643C	358B
30-60	18.5B	20.5B	7.9C	5.96A	5.78A	6.48A	6.49A	36.9B	26.0C	2.6C	3.1C	731B	377B
LSD(5%)	3.50			0.12				2.09				49.3	

Values followed by the same letter within a column for each parameter are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Table 5.23. Effect of interaction of year by depth on pre-planting soil chemical properties in the ox-plow system trial at Kulumsa.

Depth(cm)	NO <sub>3</sub> (mg kg <sup>-1</sup> )			NH <sub>4</sub> (mg kg <sup>-1</sup> )			pH (1:1 H <sub>2</sub> O)				P (mg kg <sup>-1</sup> )				Zn (mg kg <sup>-1</sup> )	
	1996	1997	1998	1996	1997	1998	1996	1997	1998	1999	1996	1997	1998	1999	1998	1999
0-15	18.7	35.2A	23.4A	9.26B	11.9	15.8A	6.13	5.37	5.81B	5.82	24.6A	14.6	11.8A	9.1A	0.61A	1.20A
15-30	20.1	32.3B	9.6B	11.0A	11.9	14.2B	6.14	5.46	6.27AB	5.91	23.6AB	13.4	4.1B	3.1B	0.45B	0.85B
30-60	19.8	32.5B	5.8C	10.2AB	12.0	11.4C	6.24	5.58	6.86A	5.98	22.4B	12.6	1.9C	1.4B	0.30C	0.38C
LSD(5%)	2.71			1.20			0.60				2.15				0.077	

Values followed by the same or no letter within a column for each parameter are not significantly different at 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

Table 5.24. Effect of interaction of year by depth on pre-planting soil chemical properties in the ox-plow system trial at Asasa

Depth(cm)	NO <sub>3</sub> (mg kg <sup>-1</sup> )			NH <sub>4</sub> (mg kg <sup>-1</sup> )			pH (1:1 H <sub>2</sub> O)				P (mg kg <sup>-1</sup> )				K (mg kg <sup>-1</sup> )		Zn (mg kg <sup>-1</sup> )	
	1996	1997	1998	1996	1997	1998	1996	1997	1998	1999	1996	1997	1998	1999	1998	1999	1998	1999
0-15	23.4A	30.2A	31.8A	9.38	9.87	12.7A	5.97B	5.46B	5.54C	5.84B	35.2A	31.6A	20.1A	15.7A	527A	473A	0.91A	1.47A
15-30	21.9AB	23.3B	20.1B	9.25	9.68	12.4A	6.02B	5.62B	5.85B	6.13A	31.7B	26.8B	8.4B	5.4B	418B	418B	0.60B	0.82B
30-60	19.7B	21.2B	7.6C	9.29	9.48	9.0B	6.29A	5.93A	6.65A	6.24A	28.6C	26.6B	3.0C	2.5C	538A	498A	0.22C	0.32C
LSD(5%)	2.63			1.51			0.17				2.15				43.6		0.13	

Values followed by the same or no letters within a column for each parameter are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999

during 1999 (Appendix 5.10). In the Kulumsa mechanised trial during 1998, RET and PARM were equal and higher than BURN at the 15-30 cm depth. In contrast, at the 30-60 cm depth, the BURN treatment resulted in the highest Zn content of the soil. In the Kulumsa mechanised trial during 1999, RET significantly increased soil Zn, while PARM = BURN, in the two uppermost soil layers. In the mechanised trial at Asasa, PARM increased soil Zn cf. the other two treatments in the 0-15 cm layer, RET < BURN = PARM in the 15-30 cm depth, and at 30-60 cm BURN significantly increased soil Zn cf. RET, while PARM was intermediate and equal to the other two treatments.

In the combined analysis across years, SM significantly affected soil Zn in the Asasa mechanised trial. RET significantly reduced the Zn content of the soil cf. BURN and PARM (Table 5.12).

The interaction between year and SM revealed a significant effect on soil Zn in the Kulumsa mechanised trial during 1999 (Table 5.25) where RET markedly increased soil Zn cf. the other two SM treatments.

**Table 5.25** Effect of interaction of year by straw management on pre-planting soil Zn (mg kg<sup>-1</sup>) in the mechanised trial at Kulumsa.

Straw management	Year	
	1998	1999
Burn	0.24	0.56B
Remove	0.25	0.57B
Retain	0.24	0.70A
LSD(5%)	0.030	

Values followed by the same or no letters within a column are not significantly different at the 5% level of the LSD test.

The interaction between year and CS revealed a significant effect on soil Zn in the Asasa mechanised trial during 1998 where the faba bean rotation significantly increased soil Zn cf. CW (Table 5.15).

The interaction between tillage and CS significantly affected soil Zn in the Asasa ox-plow trial (Table 5.17). CT combined with faba bean rotation exhibited the highest soil Zn, while MT with CW reduced soil Zn.

The interaction between SM and depth revealed significant differences in soil Zn in the soil profile in the mechanised trials at Kulumsa and Asasa (Table 5.18). In the Kulumsa mechanised trial, retention of crop stubble significantly increased soil Zn in the top two soil layers. In the Asasa mechanised trial, PARM markedly increased soil Zn relative to the other two treatments, with the exception of the 30-60 cm depth in which PARM = BURN (Table 5.18).

The interaction between tillage and depth revealed significant differences in soil Zn in the soil profile in the Kulumsa ox-plow trial (Table 5.19). CT significantly increased soil Zn cf. MT in the 0-15 cm layer, while MT increased soil Zn in the 15-30 cm layer. Zn accumulation in the surface soil layer under no-tillage probably relates to the surface accumulation of plant residues containing significant quantities of the element (Hargrove *et al.*, 1982).

The interaction of CS by depth was significant for soil Zn in the Kulumsa mechanised trial (Table 5.20). The faba bean rotation significantly increased soil Zn in the middle and lower layers of the soil (i.e., 15-30 and 30-60 cm), while, in the 0-15 cm layer, CW increased soil Zn (Table 5.20).

The interaction of year by depth revealed significant differences in soil Zn in the soil profile in the Kulumsa mechanised trial during 1998 and 1999, in the Kulumsa ox-plow trial during 1998 and 1999, and in the Asasa ox-plow trial during 1998 and 1999 (Tables 5.21, 5.23 and 5.24). In each case, soil Zn decreased with soil depth, reflecting a consistent pattern.

#### 5.2.2.7 Soil organic matter

The results of the combined ANOVA for soil OM for the mechanised and ox-plow trials (Table 5.26) at Kulumsa and Asasa revealed that year, SM, SM by year, tillage, CS, and CS by year comprised a high proportion of the total variability, reflecting a pronounced

environmental effect on soil organic matter content. In general, the Kulumsa soil had a higher level of OM than the Asasa soil.

SM practices in the mechanised trials at Kulumsa and Asasa exhibited significant effects on soil organic matter (Table 5.26). In the Kulumsa mechanised trial, RET of resulted in the highest OM content cf. PARM and BURN (Table 5.27); PARM was significantly higher than BURN (i.e.,  $RET > PARM > BURN$ ). At Asasa, RET and PARM were equal, but BURN exhibited the lowest soil organic matter content (Table 5.27). The ox-plow system trials at both sites did not exhibit any significant difference between the PARM and BURN treatments (Tables 5.26 and 5.27). Rasmussen & Collins (1991) stated that retaining crop residues on the soil surface, rather than burning or incorporating them by tillage increases soil organic C and N, due to a higher level of C and N in the surface soil layer and slower oxidation.

Tillage treatments significantly affected soil organic matter content only in the mechanised trial at Kulumsa (Table 5.26). In this trial, ZT significantly increased soil organic matter cf. CT (Table 5.27). Organic C concentration is often reduced by cultivation; this effect can be ascribed to physical disruption of protected organic matter, resulting in a higher rate of microbial breakdown (Roberts & Chan, 1990). In contrast, the mechanised trial at Asasa and both of the ox-plow trials showed no significant effect of tillage (Table 5.26).

CS significantly affected soil organic matter content in both of the mechanised trials (Table 5.26). At both locations, CW increased soil organic matter cf. the faba bean-based rotation (Table 5.27). In contrast, both of the ox-plow system trials showed no significant difference between the CS treatments (Table 5.26).

Year significantly affected soil organic matter in all trials (Table 5.26). In general, the highest soil organic matter levels were observed in the 1998 post-harvest samples, except for the Asasa ox-plow trial. The lowest results were generally observed in the 1999 pre and post and 2000 pre samples (Table 5.27).

The interaction effect of year by SM was significant for the mechanised trial at Kulumsa. With the exception of the 1999 pre sample date (in which  $RET = PARM < BURN$ ) all of the other sample dates showed that RET of crop stubble significantly increased soil organic matter cf. BURN (Table 5.28). For some sample dates, PARM was intermediate to and different from the BURN and RET treatments. In others, PARM was not different from RET. Thus, crop management systems that maintain surface residues may result in higher levels of soil organic C and N, and improve soil productivity (Havlin *et al.*, 1990).

The interaction effect of CS by tillage was significant for the mechanised trial at Kulumsa (Table 5.26). In this trial, ZT and CW resulted in the highest soil organic matter content of the combination of CT with continuous wheat or faba bean (Table 5.29). Lamb *et al.* (1985) observed that reduced tillage intensity increased surface residues and reduced the loss of OM.

**Table 5.26. Effect of crop management practices on soil organic matter content in the mechanised and ox-plow trials at Kulumsa and Asasa: ANOVA results combining nine samples taken across five years (1996-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
Year (Y)	***	***	***	***
Straw management (SM)	***	*		
SM x Y	**			
Tillage (T)	***			
T x Y				
SM x T	†			
SM x T x Y				
Cropping sequence (CS)	**	**		
CS x Y			**	
SM x CS				
SM x CS x Y				
T x CS	†			
T x CS x Y				**
SM x T x CS	*			*
SM x T x CS x Y				
Mean	3.67	3.24	3.67	3.18
C.V.(%)	7.98	10.4	8.67	7.98

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor.

The interaction effect of CS by year was significant for the mechanised trial at Kulumsa (Table 5.26). For the first three sample dates, CW significantly increased soil organic matter cf. the faba bean-based rotation (Table 5.30). For the other six sample dates, there was no effect of CS on soil OM.

**Table 5.27. Effect of crop management practices on soil organic matter content (%) in the mechanised and ox-plow trials at Kulumsa and Asasa: treatment means over nine samples taken across five years (1996-2000).**

	Kulumsa mechanised	Asasa mechanised	Kulumsa ox-plow	Asasa ox-plow
<b>Straw management</b>				
Burn	3.46C	3.12B	3.54	3.18
Removal	3.63B	3.29A	3.59	3.18
Retention	3.92A	3.32A	---	---
LSD(5%)	0.076	0.14	NS	NS
<b>Tillage</b>				
Conventional	3.50B	3.22	3.53	3.18
Zero/Minimum	3.84A	3.26	3.60	3.18
<b>Cropping sequence</b>				
Faba bean	3.62B	3.19B	3.50	3.16
Wheat	3.72A	3.29A	3.63	3.20
<b>Year</b>				
1996				
Pre-planting	3.95B	3.66B	3.62D	3.56C
Post harvest	3.76B	4.21A	3.95BC	3.85B
1997				
Pre-planting	3.99B	3.41BC	4.08B	4.25A
Post harvest	3.77B	3.53B	3.93BC	3.69BC
1998				
Pre-planting	3.61B	3.06C	3.77CD	2.86D
Post harvest	4.49A	4.11A	4.52A	3.68BC
1999				
Pre-planting	3.08C	2.36D	2.86F	2.20E
Post harvest	3.26C	2.52D	3.08E	2.33E
2000				
Pre-planting	3.10C	2.34D	3.20E	2.23E
LSD(5%)	0.48	0.35	0.21	0.21

Values within a factor level within a column and followed by the same letter(s) are not significantly different at the 5% level of the LSD test.

**Table 5.28. Effect of interaction of straw management by year on soil organic matter content (%) in the mechanised trial at Kulumsa.**

	1996		1997		1998		1999		2000
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre
Straw management									
Burn	3.65C	3.40B	3.72C	3.47B	3.51B	4.33B	3.99A	3.04B	3.00B
Removal	3.91B	3.91A	3.99B	3.64B	3.58AB	4.24B	3.13B	3.28A	3.00B
Retention	4.29A	3.96A	4.29A	4.20A	3.78A	4.92A	3.11B	3.42A	3.29A
LSD(5%)	0.23								

Values within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

Pre = Pre-planting (sample taken day of planting); Post = Post harvest (sample taken within 2 days of harvest).

**Table 5.29. Effect of interaction of cropping sequence by tillage on soil organic matter (%) in the mechanised trial at Kulumsa: means combining nine samples taken across five years (1996-2000)**

Tillage	Cropping sequence	
	Faba bean	Continuous wheat
Conventional	3.47B	3.52B
Zero	3.75AB	3.93A
LSD(5%)	0.30	

Values followed by the same letter(s) are not significantly different at the 5% level of the LSD test.

**Table 5.30. Effect of interaction of cropping sequence by year on soil organic matter (%) in the ox-plow trial at Kulumsa.**

	1996		1997		1998		1999		2000
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre
Cropping sequence									
Faba bean	3.42B	3.79B	3.93B	4.03	3.77	4.46	2.91	3.06	3.20
Continuous wheat	3.81A	4.11A	4.22A	3.84	3.78	4.59	2.80	3.10	3.19
LSD(5%)	0.25								

Values within a column followed by no letters are not significantly different at the 5% level of the LSD test.

Pre = Pre-planting (sample taken day of planting); Post = Post harvest (sample taken within 2 days of harvest).

### 5.2.3. Conclusions

Crop management practices such as stubble management, tillage and cropping sequence play an important role in maintaining an optimal soil environment. The retention of straw on the soil surface can be important for nutrient recycling. Thus, in the current study, the retention of straw on the soil surface increased the concentration of most important plant nutrients in the upper layer of the soil (i.e., 0-15 cm) cf. burning and partial removal of the straw. Furthermore, the presence of straw on or near the soil surface can reduce rain run-off and erosion, and can increase soil water content levels. Increased soil wetness can enhance the activity of micro-organisms involved in decomposing residues and changing unavailable forms of nutrients to available forms. Conservation tillage practices also increased the concentration of some important plant nutrients such as phosphorus and potassium in the upper layer of the soil as compared to conventional tillage in both the mechanised and ox-plow trials. An increased concentration of these elements in the root zone of the plant can facilitate nutrient uptake for growth and development. Cropping sequence had little effect on soil chemical properties in the current study.

No consistent trends in the changes of the different chemical soil properties over time, as a result of the treatment effects, could be identified. Many of the significant treatment effects reported for a single year might be the result of sampling difference or small analyzing inaccuracies.

## CHAPTER 6

### EFFECTS ON WEED POPULATION DYNAMICS

#### 6.1 Introduction

Weeds are a significant threat to wheat production in Ethiopia, causing large yield losses under specific conditions. Globally, wheat yields can be cut by 50% under heavy weed competition and sometimes depressed to zero (Hanson *et al.*, 1982). In Ethiopia, in some wheat growing seasons and areas, the loss can reach 70% (Tanner & Giref, 1991). Weeds, in addition to their effects on wheat yield, play a significant role in harbouring insects, serving as alternate hosts to some diseases, and increasing the cost of production (Bahrendt & Hanf, 1979).

Currently, in Ethiopia, weed control is one of the priority production constraints faced by wheat producers. In the south-eastern region, where small-scale wheat producers are predominant, problematic grass weeds, in particular, represent a serious threat to sustainable wheat production. The farmers' response to weed infestation consists of two approaches: hand weeding which has a high demand for time and labour, and chemical herbicides, primarily to control broadleaf weeds. Despite these control efforts, Ethiopian wheat farmers have not succeeded in markedly reducing yield losses. The low availability and high cost of chemical herbicides aggravate the losses due to weeds (Chilot *et al.*, 1992). Thus, to optimise and sustain yields of wheat crops in Ethiopia, it is important to study those aspects of crop husbandry which could minimise weed interference with the crop (Akobundu, 1987), and encourage wheat growth by reducing weed competition (Triplett, 1986). Such aspects may include stubble management, tillage practice and cropping sequence.

The effects of stubble management on weed infestation are diverse (Rasmussen *et al.*, 1986; Rasmussen & Rohde, 1988). Some research results indicate that stubble burning affects the incidence of viable weed seeds in the soil, reducing the seed bank, while other reports draw attention to the role of stubble retention. Some authors stress the importance of stubble in releasing toxic (i.e., allelopathic) chemicals that hinder weed growth; these effects vary with weed species (Cheam, 1986; Kimber, 1967; Heenan *et al.*, 1994).

Tillage, in addition to establishing a fine-tilth seedbed, is often considered crucial for the control of weeds. Conventional tillage brings weed seeds to the surface where they can germinate and be desiccated by subsequent tillage passes (Akobundu, 1987; Triplett, 1986). However, reduced tillage often increases the density of some problematic weed species (Tanner & Giref, 1991). Nonetheless, it has been reported that most alternate methods of weed control are more energy efficient than weed control by conventional tillage (Clements *et al.*, 1996).

Crop rotation involves the use of different species as break crops to benefit the major crop, disturbing the environment and life cycle of weeds, and thereby reducing their competitive effect on the crop. Modified cropping sequences may not eliminate interference by weeds, but can limit the build-up of weed populations and minimise shifts in species composition (Birhanu, 1985; Rezene, 1985). By growing a sequence of crops, it should be possible to disrupt the weed population due to differences in crop maturation, growth habit (i.e., reducing light infiltration), competitive ability, or allelopathic effects on weeds. The use of break crops of differing morphology can facilitate hand weeding. Also, the use of strategic rotations, with different herbicides applied to each crop species, reduces the risk of developing herbicide-resistant weed biotypes (Higgs *et al.*, 1990).

In Ethiopia, although some initial work has been conducted on the independent effects of tillage and cropping sequence on weed incidence in wheat (Asefa *et al.*, 1992), no previous study examined the integrated effects of stubble management, tillage and cropping sequence. Thus, the current study examines the effects of these crop management factors on the population dynamics of several weed species in the highlands of south-eastern Ethiopia.

## 6.2 Results and Discussion

The effects of the studied crop management factors on weed seedling population density varied with location (i.e., due to soil and climatic differences) and weed species. The results from the two mechanised trials over the period 1993-2000 are summarised in Appendices 6.1 and 6.2, while the results from the two ox-plow trials over the same period are summarised in Appendices 6.3 and 6.4. All means presented in the appendices, text and tables in this section have been detransformed from the ANOVA means.

### 6.2.1 Straw management

Total broadleaf weed (TBW) seedling density was affected by stubble management in the Kulumsa mechanised trial during 1997, 1998 and 1999 (Appendix 6.1). In 1997 and 1998, RET resulted in higher total broadleaf weed density relative to PARM and BURN, respectively. In 1999, TBW density was equal for RET and PARM and both were significantly greater than BURN. In the Asasa mechanised trial, a significant effect of stubble management on TBW was observed during 1996 and 1999. In both years, TBW values for PARM and RET were equal and greater than for BURN (Appendix 6.2). In the Asasa ox-plow trial, a significant effect of stubble management on TBW was observed during 1995, 1997 and 2000. In 1995, TBW was greater for BURN than for the PARM treatment, but, in 1997 and 2000, PARM exhibited a greater TBW density than BURN (Appendix 6.4). The ox-plow trial at Kulumsa failed to exhibit a significant effect of SM on total broadleaf density in any year (Appendix 6.3).

Total grass weed (TGW) seedling density was significantly affected by SM in the Kulumsa mechanised trial during 1995 and 2000, in the Asasa mechanised trial during 1998 and 2000, in the Kulumsa ox-plow trial during 1996 and 1997, and in the Asasa ox-plow trial during 1995, 1998 and 2000 (Appendices 6.1 to 6.4). With only one exception, TGW was density significantly lower for the BURN treatment in each trial in which a significant effect of SM was observed. In the Asasa mechanised trial during 1998, the TGW density for the BURN treatment was lower than for RET, while PARM was intermediate and equal to the other two treatments.

SM exhibited a relatively consistent effect on TBW and TGW seedling density across the trials and seasons where burning of crop stubble markedly reduced the weed seedling populations cf. the other two treatments and complete stubble retention tended to increase weed densities to the greatest extent.

In the following paragraphs, the seedling densities of the four dominant weed species in the trials are discussed for the specific years in which one or more of the treatment factors exhibited a significant effect on the density of that particular species.

*Guizotia scabra* seedling density was significantly affected by the SM treatments during 1995 in the Kulumsa mechanised trial and during 1997 in the Kulumsa ox-plow trial. In 1995, PARM exhibited the lowest density of *G. scabra*, and RET the highest. In 1997, PARM reduced the density of *G. scabra* relative to BURN (Table 6.1). Thus, the effects of SM on *G. scabra* density were consistent across the two trials.

SM affected *Amaranthus hybridus* seedling density in the two trials at Asasa during 1997 (Table 6.2). In both trials, the BURN treatment resulted in the lowest *A. hybridus* density. However, in the mechanised trial, the PARM treatment was intermediate and equal to the other two treatments while RET exhibited the highest density of this weed.

*Setaria pumila* seedling density was significantly affected by SM in the Kulumsa mechanised trial during 1995, in the Asasa mechanised trial during 1995 and 1997, and in the Kulumsa ox-plow trial during 1996 (Table 6.3). In each trial, the PARM treatment markedly increased the density of *S. pumila* cf. the other two treatments. In three of the four instances of a significant SM effect, the BURN treatment exhibited the lowest seedling density of *S. pumila*. However, in the Asasa mechanised trial during 1995, the BURN treatment was intermediate and equal to the other two treatments. Thus, SM reflected a relatively consistent effect on *S. pumila* density.

*Bromus pectinatus* seedling density was significantly affected by SM in the Kulumsa mechanised trial during 1999 and 2000, in the Asasa mechanised trial during 1997, 1998 and 2000, in the Kulumsa ox-plow trial during 1999 and 2000, and in the Asasa ox-plow trial during 1994, 1997 and 2000 (Table 6.4). In each trial, the BURN treatment resulted in the lowest *B. pectinatus* density in wheat, reflecting a consistent effect of stubble burning in reducing the seedling density of *B. pectinatus*. In the Kulumsa mechanised trial during 2000, the retention treatment exhibited the highest weed density, while the Asasa mechanised trial during the same year exhibited a higher density for PARM than RET (Table 6.4).

SM significantly affected *B. pectinatus* panicle count  $m^{-2}$  at maturity in all four trials during 2000 (Tables 6.5 and 6.6). The panicle density of *Bromus* was significantly lower in the BURN treatment for each trial (Tables 6.7 and 6.8). In the mechanised trials, the

**Table 6.1. Effects of crop management treatments on *Guizotia scabra* seedling density.**

	KuMec93	KuMec95	KuMec00	AsMec99	KuOx93	KuOx97	KuOx99	KuOx00	AsOx00
<b>Straw management</b>									
Burn	7.68	0.78AB	2.68	4.21	7.79	1.01A	4.73	4.42	2.36
Remove	6.11	0.54B	1.66	2.21	9.05	0.67B	6.85	4.84	2.28
Retain	9.49	2.19A	0.53	2.17	---	---	---	---	---
Prob.	NS	P<0.1	NS	NS	NS	*	NS	NS	NS
<b>Tillage</b>									
Conventional	8.56	0.89	2.47A	1.99B	9.68	0.69	6.20	2.63B	3.46A
Zero/Minimum	6.95	1.30	0.78B	3.73A	7.23	0.99	5.31	7.12A	1.75B
Prob.	NS	NS	**	P<0.1	NS	NS	NS	*	P<0.1
<b>Cropping sequence</b>									
Faba bean rotation	16.5A	---	1.08	3.82	12.6A	0.89	4.38B	5.26	0.62
Continuous wheat	4.52B	---	2.02	1.92	6.47B	0.75	7.28A	4.03	2.88
Prob.	***	---	NS	NS	*	NS	*	NS	NS
Mean	7.74	1.11	1.52	2.80	8.38	0.83	5.75	4.65	2.56
C.V.(%)	29.7	28.5	41.3	48.5	37.7	62.0	18.7	44.3	29.3

All values detransformed from ANOVA means [i.e., based on  $\text{SQRT}(\text{weed count}/\text{m}^2 + 0.5)$ ]. Probability levels and LSD groupings determined from ANOVA on transformed data.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 6.2. Effects of crop management treatments on *Amaranthus hybridus* seedling density.

	KuMec99	AsMec93	AsMec94	AsMec96	AsMec97	AsMec00	AsOx96	AsOx97
<b>Straw management</b>								
Burn	1.23	9.42	2.74	173.7	13.6B	1.57	8.5	10.9B
Remove	0.80	4.42	2.39	323.5	20.4AB	3.38	63.5	15.4A
Retain	1.24	9.55	2.74	547.1	28.9A	3.82	---	---
Prob.	NS	NS	NS	NS	P<0.1	NS	NS	P<0.1
<b>Tillage</b>								
Conventional	1.96A	10.0	3.91A	728.5A	31.0A	5.26A	31.6	19.4A
Zero/Minimum	0.40B	5.50	1.75B	80.5B	10.7B	1.59B	27.9	7.85B
Prob.	*	NS	*	*	*	*	NS	*
<b>Cropping sequence</b>								
Faba bean rotation	1.36	5.65B	3.11	483.5A	24.1	3.62	48.5A	10.5B
Continuous wheat	0.83	10.2A	2.74	224.5B	17.1	2.15	15.5B	15.9A
Prob.	NS	P<0.1	NS	*	NS	NS	*	*
Mean	1.08	7.62	2.74	330.7	20.5	2.85	29.8	13.0
C.V.(%)	46.9	30.9	32.6	62.2	32.8	39.5	57.4	18.1

All values detransformed from ANOVA means [i.e., based on  $\text{SQRT}(\text{weed count}/\text{m}^2 + 0.5)$ ]. Probability levels and LSD groupings determined from ANOVA on transformed data.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 6.3. Effects of crop management treatments on *Setaria pumila* seedling density.

	KuMec95	AsMec95	AsMec96	AsMec97	AsMec99	KuOx96	KuOx99	KuOx00	AsOx00
<b>Straw management</b>									
Burn	10.6C	12.2AB	2.74	7.17B	10.1	1.52B	0.74	9.35	2.03
Remove	33.7A	24.1A	2.39	11.3A	7.92	17.6A	1.60	3.62	2.81
Retain	23.8B	9.55B	3.11	7.34B	9.27	---	---	---	---
Prob.	***	P<0.1	NS	*	NS	P<0.1	NS	NS	NS
<b>Tillage</b>									
Conventional	9.42B	24.7A	4.79A	12.7A	10.6	2.29	1.65	3.82B	4.16A
Zero/Minimum	38.9A	7.23B	1.46B	4.61B	7.92	15.5	0.64	9.04A	1.06B
Prob.	***	P<0.1	*	*	NS	NS	NS	*	*
<b>Cropping sequence</b>									
Faba bean rotation	---	---	1.19B	8.80	3.31B	0.67B	2.16A	7.28	1.57
Continuous wheat	---	---	4.79A	7.62	17.9A	20.5A	0.36B	5.26	3.38
Prob.	---	---	**	NS	***	*	*	NS	NS
Mean	21.6	14.8	2.75	8.20	9.29	7.51	1.14	6.20	2.42
C.V.(%)	23.1	61.4	55.0	54.3	45.1	103.4	50.9	56.7	45.1

All values detransformed from ANOVA means [i.e., based on  $\text{SQRT}(\text{weed count}/\text{m}^2 + 0.5)$ ]. Probability levels and LSD groupings determined from ANOVA on transformed data.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 6.4. Effects of crop management treatments on *Bromus pectinatus* seedling density.

	KuMec99	KuMec00	AsMec96	AsMec97	AsMec98	AsMec00	KuOx99	KuOx00	AsOx94	AsOx96	AsOx97	AsOx00
<b>Straw management</b>												
Burn	0.00B	5.95C	1.35	2.36B	3.38B	14.2C	1.86B	12.7B	48.2B	16.2	6.47B	77.1B
Remove	2.41AB	21.1B	10.3	12.9A	50.5A	324.5A	9.27A	45.1A	147.9A	203.9	15.4A	323.5A
Retain	4.15A	66.2A	11.3	16.3A	57.7A	216.8B	---	---	---	---	---	---
Prob.	P<0.1	**	NS	*	*	**	**	***	*	NS	*	P<0.1
<b>Tillage</b>												
Conventional	0.15B	7.45B	2.89B	4.08	14.7B	60.5B	4.93	28.6	80.7	86.5	7.85	184.5
Zero/Minimum	4.53A	66.2A	12.0A	17.2	52.4A	271.8A	4.93	24.5	102.6	81.9	13.5	173.7
Prob.	*	**	*	NS	*	***	NS	NS	NS	NS	NS	NS
<b>Cropping sequence</b>												
Faba bean rotation	1.05	7.70	3.26B	7.85	---	73.5B	1.03B	21.1	57.9B	30.6B	6.42B	127.2
Continuous wheat	2.75	44.5	11.4A	11.5	---	247.0A	11.2A	32.4	103.5A	163.3A	36.1A	239.8
Prob.	NS	NS	**	NS	---	*	**	NS	*	*	P<0.1	NS
Mean	1.82	29.6	6.26	9.55	30.7	148.3	4.93	26.5	91.3	84.3	10.5	179.5
C.V.(%)	102.9	75.5	43.0	70.9	49.7	39.5	40.3	28.0	22.3	60.9	44.8	44.2

All values detransformed from ANOVA means [i.e., based on  $\text{SQRT}(\text{weed count}/\text{m}^2 + 0.5)$ ]. Probability levels and LSD groupings determined from ANOVA on transformed data.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

effects of RET and PARM were inconsistent with RET > PARM in the Kulumsa trial, while RET < PARM in the Asasa mechanised trial.

SM significantly affected *Bromus* biomass dry weight at anthesis (BDWA) in all four trials during 2000 (Tables 6.5 and 6.6). In each trial, burning of wheat stubble markedly reduced the biomass of *Bromus* (Tables 6.7 and 6.8). In the mechanised trials, there was no difference in BDWA between the PARM and RET treatments.

The density of *Bromus pectinatus* was higher than that of any other grass weed species over the trial history. *Bromus* density was significantly reduced by stubble burning during most years of the current study. Other authors (Heenan *et al.*, 1990; Rasmussen & Rohde, 1988) assessed the effect of stubble burning on *Bromus* density. Weeds such as *B. pectinatus*, which is increasingly problematic in Ethiopia, thrive under the same cultural conditions as the wheat crop and possess a similar growth habit and morphology. Thus, *B. pectinatus* is difficult to remove from wheat by hand weeding or selective herbicides, and it may be important to utilise other cultural methods, including occasional burning, to reduce the number of viable *Bromus* seeds in the soil.

Wheat biomass dry weight at anthesis was determined in the same quadrat samples used to measure *Bromus* BDWA. Wheat biomass was significantly affected by SM in all four trials during 2000 (Table 6.5 and 6.6). Wheat biomass was significantly increased by the BURN treatment in each trial (Tables 6.7 and 6.8). Thus, wheat biomass and *Bromus* biomass production responded to SM treatments in opposite directions, reflecting the opportunistic nature of the weed species. In addition, in the Kulumsa mechanised trial, PARM exhibited a greater wheat BDWA than the RET treatment.

### 6.2.2 Tillage

Of the three crop management factors, tillage exerted the most pronounced effect on weed seedling density. TBW seedling density was significantly affected by tillage in the Kulumsa mechanised trial during 1994 and 1999, in the Asasa mechanised trial during 1994, 1996, 1997, 1998 and 2000, in the Kulumsa ox-plow trial during 1994, 1998, and 1999, and in the ox-plow trial at Asasa during 1993, 1997, 1999 and 2000 (Appendices 6.1 to 6.4). In most cases, TBW density was significantly higher under ZT in the Kulumsa

mechanised and MT in the ox-plow trials. Also in Ethiopia, Tanner & Giref (1991) reported a higher density of *Guizotia scabra*, *Plantago lanceolata* and *Galium spurium* under reduced tillage. CT resulted in the highest TBW density only in the Kulumsa ox-plow trial during 1998. In contrast, in the Asasa mechanised and ox-plow trials, CT markedly increased TBW density in 8 trials, while MT increased TBW density in one instance only the Asasa ox-plow trial during 1999.

**Table 6.5. Treatment effects on different parameters of wheat and *Bromus pectinatus* in the mechanised system trial at Kulumsa and Asasa in year 2000: ANOVA results.**

	Kulumsa				Asasa			
	Bromus SD <sup>a</sup>	Bromus PCM <sup>a</sup>	Bromus BDWA <sup>a</sup>	Wheat BDWA <sup>a</sup>	Bromus SD <sup>a</sup>	Bromus PCM <sup>a</sup>	Bromus BDWA <sup>a</sup>	Wheat BDWA <sup>a</sup>
S	**	**	**	**	**	**	**	†
T	**	***	***		***	*	**	**
S x T	*	***	***		*		*	
C		*	***		*			†
S x C			***					
T x C			***					
S x T x C	*		***					
Mean	29.6	72.0	79.6	1519	148.3	278.4	210.8	425.2
C.V.(%)	75.5	54.1	47.2	19.4	39.5	20.8	39.5	29.1

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

Mean values for Bromus SD and Bromus PCM detransformed.

<sup>a</sup>SD = Seedling density (no./m<sup>2</sup>) at approx. 30 DAE; PCM = Panicle count (no./m<sup>2</sup>) at maturity; BDWA = Biomass dry weight (g/m<sup>2</sup>) at anthesis. S = Straw management; C = Cropping sequence; T = Tillage.

**Table 6.6. Treatment effects on different parameters of wheat and *Bromus pectinatus* in the ox-plow system trial at Kulumsa and Asasa in year 2000: ANOVA results.**

	Kulumsa				Asasa			
	Bromus SD <sup>a</sup>	Bromus PCM <sup>a</sup>	Bromus BDWA <sup>a</sup>	Wheat BDWA <sup>a</sup>	Bromus SD <sup>a</sup>	Bromus PCM <sup>a</sup>	Bromus BDWA <sup>a</sup>	Wheat BDWA <sup>a</sup>
S	***	†	*	†	†	*	**	***
T		*	*					
S x T	†	*						†
C		***		*		*		
S x C			†					
T x C		*			†			
S x T x C								
Mean	26.5	77.7	78.1	528.2	179.5	275.6	181.3	441.1
C.V.(%)	28.0	22.0	39.9	13.8	44.2	20.6	42.3	32.1

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

Mean values for Bromus SD and Bromus PCM detransformed.

<sup>a</sup>SD = Seedling density (no./m<sup>2</sup>) at approx. 30 DAE; PCM = Panicle count (no./m<sup>2</sup>) at maturity; BDWA = Biomass dry weight (g/m<sup>2</sup>) at anthesis.

S = Straw management; C = Cropping sequence; T = Tillage.

TGW seedling density was affected by tillage in the mechanised trial at Kulumsa during 1995, 1996, 1999 and 2000, in the mechanised trial at Asasa during 1998 and 2000, and in the ox-plow trial at Kulumsa during 1996 and 1997 (Appendices 6.1 to 6.3). In each instance of significance, ZT and MT markedly increased TGW density, reflecting a consistent effect of reduced tillage in increasing TGW density relative to conventional tillage. Kamwaga (1990) indicated a higher density of grass weeds under minimum tillage in wet conditions. The ox-plow trial at Asasa failed to exhibit a significant effect of tillage on TGW density in any year (Appendix 6.4).

Thus, the overall tendency was for weed seedling populations to increase under minimum or zero tillage vs. the conventional tillage practice. Elsewhere, weed populations have been observed to build up rapidly under zero or minimum tillage (Arshad *et al.*, 1994; Blackshaw *et al.*, 1994), necessitating the use of increasingly sophisticated post-emergence weed management practices. In contrast, some broadleaf weed species have been reported to germinate at reduced frequency under zero tillage (Clements *et al.*, 1996; Giref *et al.*, 1992).

*G. scabra* density was affected by tillage in the Kulumsa mechanised trial during 2000, in the Asasa mechanised trial during 1999, and in the ox-plow trials at Kulumsa and Asasa during 2000 (Table 6.1). In the Kulumsa mechanised and Asasa ox-plow trials, CT resulted in a higher *G. scabra* density cf. ZT and MT. In contrast, in the mechanised trial at Asasa and the ox-plow trial at Kulumsa, MT markedly increased the *G. scabra* density cf. conventional tillage. Thus, the effect of tillage on *G. scabra* density was not consistent across the site-season combinations.

Tillage significantly affected the seedling density of *Amaranthus hybridus* in the Asasa mechanised trial during 1994, 1996, 1997 and 2000, in the Kulumsa mechanised trial during 1999, and in the Asasa ox-plow trial during 1997 (Table 6.2). In all six instances of significance, CT consistently increased the population density of *A. hybridus* cf. ZT and MT. However, in the Kulumsa ox-plow trial, tillage treatment showed no effect on *A. hybridus* density in any year (Table 6.2). In a previous study, *Amaranthus* spp. exhibited poor germination on zero till plots, and *Guizotia scabra*, *Galinsoga parviflora* and *Galium*

*spurium* also occurred at lower densities under zero tillage compared to CT (Giref *et al.*, 1992).

*Setaria pumila* seedling density was significantly affected by tillage in the Kulumsa mechanised trial during 1995, in the Asasa mechanised trial during 1995, 1996 and 1997 and, in the ox-plow trials at Kulumsa and Asasa during 2000 (Table 6.3). In the Asasa mechanised and ox-plow trials, CT significantly increased the seedling density of *Setaria pumila* cf. MT (Table 6.3), but, in the Kulumsa trials, ZT and MT increased the population density of *S. pumila* (Table 6.3). Thus, the effect of tillage practice on *S. pumila* density appeared to be site specific, perhaps reflecting the prevailing soil and weather conditions.

*Bromus pectinatus* seedling density was significantly affected by tillage in the Kulumsa mechanised trial during 1999 and 2000, and in the Asasa mechanised trial during 1996, 1998 and 2000 (Table 6.4). In all five instances of significance, ZT or MT markedly increased the seedling density of *Bromus* cf. conventional tillage. Thus, the effect of tillage treatment on the population density of *Bromus* was consistent in both mechanised trials where CT significantly reduced *Bromus* density. Repeated tillage brings weed seeds to the surface and exposes them to desiccation, but tillage also buries seeds deep in the soil, creating unsuitable conditions for germination and growth, thereby reducing the density of some weeds (Akobundu, 1987). Surprisingly, no effect of tillage on *Bromus* density was observed in the two ox-plow trials.

*Bromus* panicle count  $m^{-2}$  was significantly affected by tillage in the mechanised trials at Kulumsa and Asasa, and in the ox-plow trial at Kulumsa during 2000 (Tables 6.5 and 6.6). In all three trials, ZT and MT markedly increased *Bromus* panicle density at maturity (Tables 6.6 and 6.8). Thus, the effect of tillage on *Bromus* panicle density was consistent with ZT and MT markedly increasing the *Bromus* panicle density cf. conventional tillage.

*Bromus* BDWA was significantly affected by tillage in the mechanised trials at Kulumsa and Asasa, and in the ox-plow trial at Kulumsa (Tables 6.5 and 6.6). In each trial, ZT or MT significantly increased the biomass of *B. pectinatus* cf. conventional tillage (Tables 6.7 and 6.8). Overall, conventional tillage significantly reduced *Bromus pectinatus* seedling density, panicle count  $m^{-2}$  at maturity, and BDWA.

Wheat BDWA was significantly affected by tillage only in the Asasa mechanised trial during 2000 (Table 6.5). The highest wheat BDWA was recorded in the CT treatment (Table 6.7).

**Table 6.7. Crop management effects on different parameters of wheat and *Bromus pectinatus* in the mechanised system trial at Kulumsa and Asasa in year 2000: treatment means**

	Kulumsa				Asasa			
	Bromus SD <sup>a</sup>	Bromus PCM <sup>a</sup>	Bromus BDWA <sup>a</sup>	Wheat BDWA <sup>a</sup>	Bromus SD <sup>a</sup>	Bromus PCM <sup>a</sup>	Bromus BDWA <sup>a</sup>	Wheat BDWA <sup>a</sup>
SM								
Burn	5.95C	8.37C	16.1B	1777A	14.2C	97.6C	66.8B	520.2A
Removal	21.1B	109.4B	120.4A	1495B	324.5A	442.0A	273.5A	338.6B
Retention	66.2A	145.5A	102.2A	1286C	216.8B	367.4B	292.2A	416.8AB
LSD(5%)	2.92	9.50	46.6	164	22.0	22.4	98.05	149.0
Tillage								
CT	7.45B	12.0B	7.52B	1705	60.5B	205.8B	144.1B	518.7A
ZT/MT	66.2A	181.5A	151.6A	1334	271.8A	362.4A	277.6A	331.7B
CS								
FB	7.70	48.4B	40.7B	1583	73.5B	250.4	197.1	463.8
CW	44.5	100.2A	118.4A	1456	247.0A	308.4	224.5	386.6

Values followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.

Mean and LSD values for Bromus SD and Bromus PCM detransformed.

<sup>a</sup>SD = Seedling density (no./m<sup>2</sup>) at approx. 30 DAE; PCM = Panicle count (no./m<sup>2</sup>) at maturity; BDWA = Biomass dry weight (g/m<sup>2</sup>) at anthesis.

SM = Straw management, CS = Cropping sequence; CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage; FB = Faba bean rotation with wheat (1 year in 3); CW = Continuous wheat.

**Table 6.8. Crop management effects on different parameters of wheat and *Bromus pectinatus* in the ox-plow system trial at Kulumsa and Asasa in year 2000: treatment means**

	Kulumsa				Asasa			
	Bromus SD <sup>a</sup>	Bromus PCM <sup>a</sup>	Bromus BDWA <sup>a</sup>	Wheat BDWA <sup>a</sup>	Bromus SD <sup>a</sup>	Bromus PCM <sup>a</sup>	Bromus BDWA <sup>a</sup>	Wheat BDWA <sup>a</sup>
SM								
Burn	12.7B	39.1	39.6B	577.0	77.1	109.2B	70.8B	521.7A
Removal	45.1A	129.3	116.6A	479.2	323.5	517.6A	291.8A	360.5B
Tillage								
CT	28.6	56.5B	66.1B	529.1	184.5	299.3	164.7	478.3
MT	24.5	102.2A	90.1A	527.3	173.7	252.9	197.9	403.9
CS								
FB	21.1	52.0B	67.4	567.8A	127.2	221.8B	161.8	437.7
CW	32.4	108.4A	88.9	488.6B	239.8	335.3A	200.8	444.5

Values followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.

Mean values for Bromus SD and Bromus PCM detransformed.

<sup>a</sup>SD = Seedling density (no./m<sup>2</sup>) at approx. 30 DAE; PCM = Panicle count (no./m<sup>2</sup>) at maturity; BDWA = Biomass dry weight (g/m<sup>2</sup>) at anthesis.

SM = Straw management, CS = Cropping sequence; CT = Conventional tillage; MT = Minimum tillage; FB = Faba bean rotation with wheat (1 year in 3); CW = Continuous wheat.

### 6.2.3 Cropping sequence

TBW seedling density was affected significantly by CS in the Kulumsa mechanised trial during 1993 and in the Asasa mechanised trial during 1996, 1999 and 2000 (Appendices 6.1 and 6.2). In each instance of significance, the faba bean rotation exhibited a significantly increased TBW density cf. the continuous wheat treatment. The ox-plow trials at both sites failed to exhibit a significant effect of CS on TBW density. In the mechanised trials, most of the broadleaf weed species were higher in density in the legume-wheat crop rotation, implying that the residual N remaining after the legume harvest enhanced the vigour of the broadleaf weed species.

TGW seedling density was significantly affected by CS in the Kulumsa mechanised trial during 1997 and 2000, in the Asasa mechanised trial during 1996 and 2000, in the Kulumsa ox-plow trial during 1996 and 1997, and in the Asasa ox-plow trial during 1996 (Appendices 6.1 to 6.4). In six instances of significance, continuous wheat significantly increased TGW seedling density cf. the legume-wheat rotation. Thus, rotation of wheat with faba bean is a promising means of reducing grass weed densities in wheat. The build up of grass weed species in continuous wheat production systems has been reported elsewhere (Blackshaw *et al.*, 1994; Heenan *et al.*, 1990).

*G. scabra* seedling density was significantly affected by CS in the mechanised trial at Kulumsa during 1993 and in the ox-plow trial at Kulumsa during 1993 and 1999 (Table 6.1). During 1993 in both trials, the faba bean rotation resulted in a higher *G. scabra* density than CW. However, in the ox-plow trial at Kulumsa during 1999, *G. scabra* density was significantly higher in CW than in the faba bean rotation (Table 6.1). The mechanised and ox-plow trials at Asasa did not exhibit a significant effect of CS on *G. scabra* density in any year (Table 6.1).

CS significantly affected the seedling density of *Amaranthus hybridus* in the mechanised trial at Asasa during 1993 and 1996, and in the ox-plow trials at Asasa during 1996 and 1997 (Table 6.2). During 1993 in the Asasa mechanised trial and during 1997 in the Asasa ox-plow trial *A. hybridus* density was significantly increased by CW. In contrast, during 1996 in both trials at Asasa, *A. hybridus* density was markedly increased in the faba bean rotation cf. CW (Table 6.2). The mechanised and ox-plow trials at Kulumsa failed to

exhibit a significant effect of CS on *A. hybridus* density in any season throughout the trial period (Table 6.2). Thus, the effect of CS on *A. hybridus* density varied markedly with location and season.

*Setaria pumila* seedling density was significantly affected by CS in the mechanised trial at Asasa and in the ox-plow trial at Kulumsa during 1996 and 1999 (Table 6.3). During 1996 and 1999 in the Asasa mechanised trial and during 1996 in the Kulumsa ox-plow trial, CW significantly increased the population density of *S. pumila* (Table 6.3), while during 1999 in the Kulumsa ox-plow trial, the faba bean rotation markedly increased the density of *S. pumila* in wheat.

CS significantly affected *Bromus* seedling density in the Asasa mechanised trial during 1996 and 2000, in the Kulumsa ox-plow trial during 1999, and in the Asasa ox-plow trial during 1994, 1996 and 1997 (Table 6.4). For all instances of significance, CW increased the population density of *Bromus* in wheat (Table 6.4), reflecting a higher infestation of *Bromus* in continuous wheat production systems. Herbicidal weed control of other grass weeds by the application of fenoxaprop-p-ethyl may have contributed to the growth in numbers of this opportunistic weed species since the chemical does not control *Bromus* species.

*Bromus* panicle count  $m^{-2}$  was significantly affected by CS in three trials during year 2000, namely the Kulumsa mechanised and ox-plow trials and the Asasa ox-plow trial (Tables 6.5 and 6.6). In each of these three trials, CW markedly increased *Bromus* panicle density cf. the faba bean rotation (Tables 6.7 and 6.8). The Asasa mechanised trial failed to exhibit a significant effect of CS on the panicle count of *Bromus*.

CS only affected *Bromus* BDWA in the Kulumsa mechanised trial during 2000 (Table 6.5) where the highest *Bromus* biomass production was observed in the CW treatment cf. the faba bean rotation (Table 6.7).

Wheat BDWA was significantly affected by CS in the Asasa mechanised trial (Table 6.5) and in the Kulumsa ox-plow trial (Table 6.6). In each trial, the faba bean rotation increased wheat biomass production relative to the continuous wheat treatment.

#### 6.2.4 Interactions

The interaction effect of SM by tillage was significant in the Kulumsa mechanised trial for *Bromus* seedling density, panicle count at maturity and BDWA (Table 6.5). For each parameter, there was no effect of SM treatment under CT, but, under ZT, BURN significantly reduced the weed parameters cf. the other SM treatments (Table 6.9). Examined from another perspective, ZT increased each *Bromus* parameter when combined with partial removal or complete retention of stubble; however, under stubble burning, ZT did not significantly increase any of the measured *Bromus* parameters (Table 6.9). In the Asasa mechanised trial, a similar interaction effect was observed for *Bromus* seedling density and BDWA (Table 6.9) where BURN exhibited the lowest values under both tillage systems, while MT combined with PARM or RET markedly increased the seedling density and biomass of *Bromus*. CT combined with PARM or RET was intermediate for the same parameters in the Asasa trial. In the Kulumsa ox-plow trial, the interaction effect was significant only for the *Bromus* panicle count at maturity. In this trial, BURN combined with CT, resulted in the lowest panicle count cf. the other three treatment combinations (Table 6.9).

The interaction effect of SM by CS was significant only for *Bromus* BDWA in the Kulumsa mechanised trial during 2000 (Table 6.5). Under continuous wheat production, BDWA followed the ranking PARM > RET > BURN, but in the faba bean rotation, SM exerted a lesser and non-significant effect on BDWA (Table 6.10). Alternatively, it was apparent that, under the BURN treatment, CS had no effect on BDWA. In contrast, BDWA increased markedly under continuous wheat production combined with either complete retention or partial removal of stubble.

The interaction effect of tillage by CS was significant in the Kulumsa mechanised trial for *Bromus* BDWA (Table 6.5) and in the Kulumsa ox-plow trial for *Bromus* panicles m<sup>-2</sup> (Table 6.6). The highest biomass production of *Bromus* was recorded in the combination of ZT with CW (Table 6.11). However, under conventional tillage, the faba bean rotation was equal to CW.

Table 6.9. Effects of interaction of straw management by tillage on different parameters of wheat and *Bromus pectinatus* in the mechanised and ox-plow system trials at Kulumsa and Asasa in year 2000.

SM	Kulumsa mechanised						Asasa mechanised				Kulumsa ox-plow	
	Bromus SD <sup>a</sup>		Bromus PCM <sup>a</sup>		Bromus BDWA <sup>a</sup>		Bromus SD <sup>a</sup>		Bromus BDWA <sup>a</sup>		Bromus PCM <sup>a</sup>	
	CT	ZT	CT	ZT	CT	ZT	CT	MT	CT	MT	CT	MT
Burn	2.63C	10.5BC	6.16B	10.9B	5.82B	26.4B	12.4C	15.1C	60.2C	73.4C	14.2B	75.9A
Remove	5.26C	47.2B	11.9B	302.3A	6.72B	234.0A	150.8B	565.9A	159.5BC	387.6A	127.2A	131.8A
Retain	17.8BC	204.0A	19.8B	387.6A	10.03B	194.3A	57.3BC	479.1A	212.6B	371.8A	---	---
LSD(5%)	18.2		11.9		48.5		34.4		101.3		10.4	

Values followed by the same letters within each parameter are not significantly different at the 5% level of the LSD test.

Treatment mean and LSD values for Bromus SD and Bromus PCM detransformed.

<sup>a</sup>SD = Seedling density (no./m<sup>2</sup>) at approx. 30 DAE; PCM = Panicle count (no./m<sup>2</sup>) at maturity; BDWA = Biomass dry weight (g/m<sup>2</sup>) at anthesis.

SM = Straw management; CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage.

Table 6.10. Effects of interaction of straw management by cropping sequence on *Bromus pectinatus* biomass dry weight (g) in the mechanised system trial at Kulumsa in year 2000.

SM	Cropping sequence	
	FB	CW
Burn	18.9CD	13.3D
Removal	36.8CD	203.9A
Retain	66.5C	137.9B
LSD(5%)	53.1	

Values followed by the same letters are not significantly different at the 5% level of the LSD test.

SM = Straw management; FB = Faba bean rotation with wheat (1 year in 3); CW = Continuous wheat.

In the ox-plow trial, the highest *Bromus* panicle count was recorded in the combination of MT with CW and the other three treatment combinations were lower or equal to each other (Table 6.11). Thus, the interactions reveal that crop rotation with faba bean was beneficial in reducing *Bromus* parameters, primarily in conjunction with reduced tillage.

In summary, the interaction effects revealed that stubble burning ameliorated the negative effects of either reduced tillage or continuous wheat production on the various *Bromus* parameters measured in the current study. Crop rotation with faba bean at least partially counteracted the negative effects of reduced tillage on *Bromus* infestation in wheat.

**Table 6.11. Effects of interaction of tillage by cropping sequence on different parameters of *Bromus pectinatus* in the mechanised and ox-plow system trials at Kulumsa in year 2000.**

	Kulumsa mechanised		Kulumsa ox-plow	
	Bromus BDWA <sup>a</sup>		Bromus PCM <sup>a</sup>	
	FB	CW	FB	CW
Tillage				
CT	7.76C	7.29C	49.3B	64.0B
ZT/MT	73.7B	229.5A	54.7B	163.3A
LSD(5%)	38.6		7.01	

Values followed by the same letters within each parameter are not significantly different at the 5% level of the LSD test.

<sup>a</sup>PCM = Panicle count (no./m<sup>2</sup>) at maturity; BDWA = Biomass dry weight (g/m<sup>2</sup>) at anthesis.

CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage; FB = Faba bean rotation with wheat (1 year in 3);

CW = Continuous wheat.

### 6.3 Conclusions

Weed species responded differentially to the crop management factors included in the current study. Partial removal or retention of stubble tended to increase the density of some broadleaf weed species, contrasting with the reduced weed density observed under the burn treatment. Total grass weed density showed a consistent pattern across trials where burning crop stubble markedly reduced the weed population cf. total or partial retention of stubble. The effects of tillage also varied with weed species and location. Broadleaf weeds did not exhibit a consistent response to tillage in either the ox-plow or mechanised trials. Grass weeds, however, markedly increased in density under minimum or zero tillage.

Broadleaf weeds did not vary markedly in response to cropping sequence, but most grass weeds decreased in the faba bean rotation.

The density of *Bromus pectinatus* could be reduced by occasional burning of crop stubble, by conventional tillage, and by adopting crop rotation with faba bean. Since no herbicide is currently available to effectively control this problematic weed species in Ethiopia, care must be taken to avoid inducing a weed population shift towards *B. pectinatus* (i.e., by practicing continuous wheat production under reduced tillage with stubble retention). Furthermore, the factor interactions revealed that if reduced tillage practices are to be introduced for wheat production, crop rotation and periodic stubble burning will be essential to minimise the build-up of the *Bromus* infestation.

## CHAPTER 7

### EFFECTS ON ROOT DISEASES

#### 7.1 Introduction

Take-all and eyespot are economically important diseases of small grain cereals in many regions of the world. For both diseases, wheat is regarded as the most susceptible cereal grain species (Wiese, 1977; Zogg, 1980).

Wheat crops affected by take-all disease exhibit bleached spikes, uneven plant height, and irregular maturity (Wiese, 1977; Zogg, 1980). A black-brown dry rot extends to the crown and basal portion of the culm, while a superficial, dark, shiny mycelial plate beneath the lowest leaf sheath is diagnostic. When roots and crowns are damaged by take-all to the extent that symptoms such as "white heads" are obvious, grain yields are often reduced by 50% or more (Bockus, 1983).

Wheat plants infected by eyespot exhibit elliptical or "eye" shaped lesions on the basal portion of the stem, and a grayish, cottony mycelium inside the internode is diagnostic (Wiese, 1977). Yield reduction often occurs when half of the circumference of the stem is girdled by an eyespot lesion (Scott & Hollins, 1974).

Although both diseases appear to be widespread and prevalent in wheat crops in Ethiopia (Eshetu & Yitbarek, 1983), few studies of potential control measures have been conducted. As the causal pathogens are both soil- and trash-borne, crop debris is an important source of disease inoculum (Jenkyn & Plumb, 1981). In general, agronomic practices are the major determinants of the threat posed by soil- and trash-borne pathogens (Jenkyn & Plumb, 1981).

Conservation tillage (CT) commonly involves the retention of crop stubble on the soil surface, as a result of a reduction in the number of tillage operations. As a general principle, CT combined with stubble retention reduces the risk of soil erosion and increases water infiltration and storage in the soil profile (Harte & Armstrong, 1983). However, the retention of stubble residues on the soil surface has frequently been

associated with an increased incidence of crop pests and diseases (Moore & Cook, 1984; Throckmorton, 1986; de Boer *et al.*, 1993).

Rotation and cropping sequence trials in Ethiopia have established the importance of including leguminous crop species in wheat-based cropping systems to improve yields and sustain production (Tanner *et al.*, 1999). The interruption of weed, disease and insect life cycles is one of the important benefits generally cited for crop rotation (Herrman & Wiese, 1985).

In Ethiopia, the effects of stubble management (SM), tillage, and cropping sequence (CS) practices on the trash- and soil-borne diseases of wheat have not been adequately studied. Thus, a long-term study was initiated to examine the effects of integrated crop management practices on the incidence of take-all and eyespot diseases of wheat in Ethiopia.

## 7.2 Results

### 7.2.1 Take-all incidence

The results of the combined analyses of variance for take-all incidence (Tables 7.1 and 7.2) revealed that the year effect comprised a high proportion of total variability, reflecting both a pronounced environmental effect on the incidence of the pathogen and changes in the wheat cultivar sown over the trial duration. However, no consistent trends were apparent. Take-all incidence was highest during the 1999 season for three trials, while take-all incidence was highest in 1994 for the Asasa mechanised trial (Table 7.2). Mean take-all incidence was similar across the four trials of this study (Table 7.2).

Stubble management practice had no effect on take-all incidence in any of the four trials, and SM by year interaction was also non-significant in each trial (Table 7.1).

Tillage practice exerted a significant effect on take-all incidence in three of the trials (Table 7.1), and, in each case, tillage by year interaction was non-significant. CT significantly reduced the incidence of take-all in the mechanised trials at both locations, but the reduction was more pronounced at Asasa [MT] than at Kulumsa [ZT] (Table 7.2). In the ox-plow trials, MT reduced the incidence of take-all at Kulumsa but not at Asasa.

Cropping sequence affected take-all incidence in the ox-plow trial at Kulumsa. The main effect of CS was highly significant, while CS by year interaction was non-significant (Table 7.1). Take-all incidence was reduced in wheat following a faba bean precursor crop, in both the first and second years following faba bean when compared to the disease level recorded in continuous wheat (Table 7.2).

**Table 7.1. Results of combined analysis of variance over years for take-all incidence<sup>a</sup> measured during 1994, 1996, 1997 and 1999 in the trials conducted at Asasa and Kulumsa.**

Source of Variation	Ox-plow			Mechanized		
	d.f.	MS <sup>b</sup>		d.f.	MS <sup>b</sup>	
		Asasa	Kulumsa		Asasa	Kulumsa
Year (Y)	3	14.13***	16.5**	3	9.98*	27.0**
Residual	8	0.800	1.52	8	1.93	2.72
Stubble management (SM)	1	0.032	0.016	2	2.63	0.589
Y x SM	3	0.156	0.877	6	2.20	0.586
Residual	8	0.356	0.712	16	1.72	0.907
Tillage (T)	1	2.24	21.2***	1	29.7***	5.44†
Y x T	3	0.918	1.85	3	2.45	1.71
SM x T	1	2.60	0.337	2	0.682	0.623
Y x SM x T	3	1.06	1.71	6	2.55	1.11
Residual	16	1.22	1.18	24	1.33	1.59
Cropping sequence (CS)	1	1.90	9.28**	1	1.81 <sup>c</sup>	3.41 <sup>c</sup>
Y x CS	3	0.434	1.15	3	7.67**	9.08***
SM x CS	1	0.323	1.61	2	0.136	0.251
Y x SM x CS	3	1.02	0.998	6	2.00	0.867
T x CS	1	0.001	3.63	1	0.001	2.77
Y x T x CS	3	1.70†	2.39*	3	1.07	1.77
SM x T x CS	1	0.041	6.59**	2	0.791	5.49**
Y x SM x T x CS	3	0.360	1.69	6	0.397	1.08
Residual	32	0.745	0.764	48	1.27	1.01

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

<sup>b</sup> Mean square values.

<sup>c</sup> Indicates a mean square value that is non-significant in comparison to the corresponding significant ( $P < 0.05$ ) interaction with year (i.e., considering year as a random factor).

The main effect of CS was obscured in both mechanised trials by the significant interaction of CS with year (Table 7. 1). Take-all levels were lower in wheat following faba bean during 1994 at Asasa and during 1996 at Kulumsa, but were higher during 1999

at Kulumsa (Table 7.3). No significant effects of CS on take-all incidence were apparent for the remaining five site-season combinations.

The two-way interaction effects among SM, tillage and CS were non-significant in all four trials (Table 7.1) but the three-way interaction effect of SM by tillage by CS was significant in the two trials at Kulumsa. The 12 three-way interaction means for take-all in the mechanised trial at Kulumsa (Table 7.4) revealed that stubble burning combined with conventional tillage markedly increased take-all incidence in wheat grown in rotation with faba bean. Nonetheless, the main effect of tillage was apparent in the 12 interaction means but the three lowest levels of take-all were associated with CT. The inconsistency of the effect of CS was also apparent within this set of interaction means. In contrast, the eight interaction means for the ox-plow trial at Kulumsa more clearly demonstrated the disease-reducing effects of CT and of rotation with faba bean.

**Table 7.2. Treatment main effect and year means for take-all incidence<sup>a</sup> measured in the trials conducted at Asasa and Kulumsa.**

	Ox-plow		Mechanized	
	Asasa	Kulumsa	Asasa	Kulumsa
Year				
1994	0.99 C	1.45 B	2.87 A	1.31 B
1996	1.09 C	1.97 B	1.89 B	1.61 B
1997	1.99 B	3.05 A	1.66 B	1.73 B
1999	2.60 A	3.15 A	2.07 B	3.25 A
LSD(0.05)	0.60	0.82	0.76	0.90
Stubble management				
Burn	1.65	2.42	2.37	2.10
Removal	1.69	2.39	1.91	1.94
Retention	-	-	2.08	1.89
LSD(0.05)	NS	NS	NS	NS
Tillage				
Conventional	1.52	2.88 A	2.58 A	2.17 A
Zero or Minimum <sup>b</sup>	1.82	1.94 B	1.67 B	1.78 B
Cropping sequence				
Faba bean rotation	1.53	2.09 B	2.01	2.13
Continuous wheat	1.81	2.72 A	2.23	1.82
Mean	1.67	2.41	2.12	1.98
C.V.(%)	51.7	36.3	53.1	50.9

Values within each factor within a column followed by the same letter or no letters are not significantly different at the 5% level of the LSD test.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

<sup>b</sup> ZT for Kulumsa mechanized; MT for the other trials.

**Table 7.3. Effects of interaction of year by cropping sequence on take-all incidence<sup>a</sup> in the mechanized trials at Asasa and Kulumsa**

	Asasa		Kulumsa	
	F <sup>b</sup>	W	F	W
Year				
1994	2.13 B	3.61 A	1.50	1.13
1996	2.08	1.69	1.16 B	2.06 A
1997	1.49	1.83	1.83	1.64
1999	2.33	1.81	4.03 A	2.47 B
LSD(0.05)	0.755		0.714	
Probability	**		***	

\*\* , \*\*\* Statistically significant at  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

Values within a year and for each trial followed by a unique letter differ at the 5% level of the LSD test.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

<sup>b</sup> F = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

### 7.2.2 Eyespot incidence

The results of the combined analyses of variance for eyespot incidence (Table 7.5) revealed that year effect is the major component of total variability, reflecting environmental influences on pathogenicity and cultivar differences in susceptibility. As was the case for take-all incidence, there was no apparent trend over time for eyespot incidence (Table 7.6). Eyespot incidence was highest in 1999 for all four trials, two trials exhibited similar disease levels in 1994 while another trial exhibited a similarly high disease level in 1997.

Stubble management main effects on eyespot incidence were non-significant in three trials, while in the Kulumsa mechanised trial the SM main effect was obscured by the significant year by SM interaction (Table 7.5). In the Kulumsa mechanised trial, full retention of crop stubble increased eyespot incidence relative to partial removal in 1996 and 1999, and increased disease incidence relative to stubble burning in 1996 and 1997 (Table 7.7). The effect of SM on eyespot incidence in 1994 was not significant. In the ox-plow trial at Asasa, SM effects were inconsistent because the SM effect was not significant in 1996 and 1997; but the eyespot incidence was higher in 1994 under partial removal relative to stubble burning. The opposite response to burning was observed in 1999 (Table 7.7).

Table 7.4. Mean take-all incidence for each treatment from the combined analysis over years of measurements during 1994, 1996, 1997 and 1999 at Asasa and Kulumsa.

Crop management practice <sup>a</sup>			Disease score <sup>b</sup>			
			Ox-plow		Mechanized	
			Tillage	Sequence	Asasa	Kulumsa
Burn	Conv	F	1.27	1.93 D	2.98	2.74 A
Burn	Conv	W	1.40	3.73 A	2.94	2.11 ABCD
Burn	CT	F	1.87	2.02 D	1.66	1.61 CDE
Burn	CT	W	2.07	1.99 D	1.91	1.94 ABCDE
Rem	Conv	F	1.48	2.81 BC	2.04	1.86 BCDE
Rem	Conv	W	1.92	3.04 AB	2.61	2.25 ABC
Rem	CT	F	1.50	1.61 D	1.50	2.45 AB
Rem	CT	W	1.85	2.11 CD	1.49	1.19 E
Ret	Conv	F	-	-	2.38	1.96 ABCDE
Ret	Conv	W	-	-	2.51	2.10 ABCD
Ret	CT	F	-	-	1.50	2.17 ABCD
Ret	CT	W	-	-	1.95	1.34 DE
Mean			1.67	2.41	2.12	1.98
C.V.(%)			51.7	36.3	53.1	50.9
LSD(0.05)			NS	0.727	NS	0.825
F-test:	Stubble management (SM)		NS	NS	NS	NS
	Tillage (T)		NS	***	***	†
	SM x T		NS	NS	NS	NS
	Cropping sequence (CS)		NS	**	NS	NS
	SM x CS		NS	NS	NS	NS
	T x CS		NS	NS	NS	NS
	SM x T x CS		NS	**	NS	**

†, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

Values within a column followed by the same letter(s) are not different at the 5% level of the LSD test.

<sup>a</sup> Burn = Complete burn of crop stubble; Rem = Partial removal of crop stubble; Ret = Complete retention of crop stubble; Conv = Conventional tillage; CT = Conservation tillage; F = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

<sup>b</sup> Transformed using the square root of (weighted percent severity score + 0.5).

**Table 7. 5. Results of combined analysis of variance over years for eyespot incidence<sup>a</sup> measured during 1994, 1996, 1997 and 1999 in the trials conducted at Asasa and Kulumsa.**

Source of Variation	Ox-plow			Mechanized		
	d.f.	MS <sup>b</sup>		d.f.	MS <sup>b</sup>	
		Asasa	Kulumsa		Asasa	Kulumsa
Year (Y)	3	36.5***	76.5***	3	24.9**	83.5***
Residual	8	2.14	0.646	8	2.18	1.66
Stubble management (SM)	1	0.270	0.149	2	2.76	5.88 <sup>c</sup>
Y x SM	3	7.21**	0.526	6	0.706	2.63*
Residual	8	0.560	1.14	16	1.60	0.949
Tillage (T)	1	1.07	3.65†	1	2.16	0.308
Y x T	3	1.53	1.02	3	0.624	2.08†
SM x T	1	7.97†	0.144	2	0.944	4.65**
Y x SM x T	3	0.532	0.361	6	5.03**	1.62
Residual	16	2.62	0.937	24	1.15	0.826
Cropping sequence (CS)	1	1.84	1.31	1	0.400	7.69 <sup>c</sup>
Y x CS	3	1.74	0.495	3	2.85†	8.89***
SM x CS	1	0.263	1.22	2	0.179	0.598
Y x SM x CS	3	0.634	1.12	6	1.55	0.804
T x CS	1	0.270	1.79	1	0.782	0.229
Y x T x CS	3	1.29	1.75†	3	0.401	0.163
SM x T x CS	1	1.38	4.10*	2	0.250	0.487
Y x SM x T x CS	3	1.92	0.854	6	1.45	4.46**
Residual	32	1.48	0.681	48	1.22	1.24

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

<sup>b</sup> Mean square values.

<sup>c</sup> Indicates a mean square value that is non-significant in comparison to the corresponding significant ( $P < 0.05$ ) interaction with year (i.e., considering year as a random factor).

Tillage main effect and tillage by year interaction were not significant in most cases (Table 7.5). The exceptions, at only the 10% level of significance, were tillage in the Kulumsa ox-plow trial and tillage by location interaction in the Kulumsa mechanised trial. In the Kulumsa ox-plow trial, MT modestly reduced the incidence of take-all. In the Kulumsa mechanised trial, ZT increased the incidence of eyespot in 1997, while in the other three years there was no significant effect of tillage.

The SM by tillage effect was the only significant two-way interaction affecting eyespot incidence (Table 7.2). SM by tillage interaction was highly significant in the Kulumsa mechanised trial and, to a lesser extent, in the Asasa ox-plow trial. Although the two highest levels of eyespot in the Kulumsa mechanised trial occurred under complete stubble

retention (Table 7.8), it did not differ from stubble burning with conventional tillage or partial removal of stubble with ZT. Zero tillage apparently increased the disease incidence with partial removal of stubble, but not for the other two SM practices. In the Asasa ox-plow trial, conventional tillage with stubble burning resulted in the lowest eyespot incidence, but was not significantly different from MT with partial removal of stubble.

**Table 7.6. Treatment main effect and year means for eyespot incidence<sup>a</sup> measured in the trials conducted at Asasa and Kulumsa.**

	Ox-plow		Mechanized	
	Asasa	Kulumsa	Asasa	Kulumsa
<b>Year</b>				
1994	4.11 A	1.60 B	3.40 A	1.10 B
1996	1.76 B	1.32 B	2.14 B	1.79 B
1997	2.63 B	4.47 A	2.02 B	2.86 B
1999	4.35 A	4.62 A	3.61 A	4.59 A
LSD(0.05)	0.97	0.54	0.80	0.90
<b>Stubble management</b>				
Burn	3.16	3.04	2.58	2.32
Removal	3.27	2.96	2.75	2.45
Retention	-	-	3.05	2.98
LSD(0.05)	NS	NS	NS	NS
<b>Tillage</b>				
Conventional	3.11	3.20	2.91	2.54
Zero or Minimum <sup>b</sup>	3.32	2.81	2.67	2.63
<b>Cropping sequence</b>				
Faba bean rotation	3.08	2.89	2.85	2.82
Continuous wheat	3.35	3.12	2.74	2.36
Mean	3.21	3.00	2.79	2.59
C.V.(%)	37.9	27.5	39.5	43.0

Values within each factor within a column followed by the same letter or no letters are not significantly different at the 5% level of the LSD test.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

<sup>b</sup> ZT for Kulumsa mechanized; MT for the other trials.

The cropping sequence main effect and CS by year interaction were not significant for both ox-plow trials. For the mechanised trials, however, significance was observed for the CS by year interaction (Table 7.5). Essentially, these significant interaction effects were attributable to the Asasa trial in 1996 and the Kulumsa trial in 1999. In both trials, eyespot incidence was increased in wheat in rotation with faba bean where the effect of CS was not significant for the other six site-season combinations (Table 7.9).

The three-way interaction effect for SM by tillage by CS, was only significant in the Kulumsa ox-plough trial (Table 7.5). The eight three-way interaction means for eyespot incidence in the Kulumsa ox-plough trial (Table 7.10) revealed that straw burning combined with conventional tillage in wheat in rotation with faba bean resulted in the lowest absolute level of eyespot; although this level of eyespot did not differ significantly with the disease incidence in the four treatments involving CT.

**Table 7.7. Effects of interaction of year by stubble management on eyespot incidence<sup>a</sup> in the Asasa ox-plow and Kulumsa mechanized trials.**

	Asasa ox-plow		Kulumsa mechanized		
	Burn <sup>b</sup>	Remove	Burn	Remove	Retain
Year					
1994	3.35 B	4.88 A	0.921	1.14	1.23
1996	1.86	1.65	1.41 B	1.51 B	2.46 A
1997	2.53	2.74	2.07 B	3.21 A	3.31 A
1999	4.91 A	3.80 B	4.89 A	3.95 B	4.94 A
LSD(0.05)	0.705		0.843		
Probability	**		*		

\*, \*\* Statistically significant at  $0.01 < P < 0.05$  and  $0.001 < P < 0.01$ , respectively.

Values within a year and for each trial followed by a unique letter differ at the 5% level of the LSD test.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

<sup>b</sup> Burn = Complete burn of crop stubble; Remove = Partial removal of crop stubble; Retain = Complete retention of crop stubble.

**Table 7.8. Effects of interaction of tillage by stubble management on eyespot incidence<sup>a</sup> in the Asasa ox-plow and Kulumsa mechanized trials**

	Asasa ox-plow		Kulumsa mechanized	
	Tillage practice		Tillage practice	
	Conventional	Minimum	Conventional	Zero
Stubble management				
Burn stubble	2.77 C	3.45 AB	2.52 AB	2.13 B
Partial removal	3.56 A	3.09 BC	2.06 B	2.85 A
Complete retention	-	-	3.05 A	2.92 A
LSD	0.45		0.54	
Probability	†		**	

†, \*\* Interaction statistically significant at  $0.1 < P < 0.05$ , and  $0.001 < P < 0.01$ , respectively.

Values within each trial followed by the same letter(s) are not different at the 10 and 5% levels of the LSD test for the Asasa ox-plow and Kulumsa mechanized trials, respectively.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

**Table 7. 9. Effects of interaction of year by cropping sequence on eyespot incidence<sup>a</sup> in the mechanized trials at Asasa and Kulumsa**

	Asasa		Kulumsa	
	F <sup>b</sup>	W	F	W
Year				
1994	3.50	3.31	1.17	1.02
1996	2.57 A	1.71 B	1.54	2.05
1997	1.80	2.23	3.04	2.68
1999	3.52	3.71	5.52 A	3.67 B
LSD(0.05)	0.740		0.746	
Probability	†		***	

†, \*\*\* Statistically significant at  $0.1 < P < 0.05$  and  $P < 0.001$ , respectively.

Values within a year and for each trial followed by a unique letter differ at the 5% level of the LSD test.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

<sup>b</sup> F = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

### 7.2.3 Simple correlations

The simple correlations (Table 7.11), calculated for individual plot disease scores and grain yields within each trial, revealed that the incidence of take-all and eyespot increased concurrently. The two diseases exhibited significant positive associations in ten trials vs. a negative association in only one trial. In general, take-all incidence was negatively related with wheat grain yield because significant negative correlations were observed in five trials and no positive associations occurred. Conversely, eyespot incidence was not strongly correlated with wheat grain yield; with positive associations in three trials, suggesting that factors conducive to grain yield also enhanced eyespot incidence.

### 7.3 Discussion

The traditional tillage practice of peasant farmers in Ethiopia involves multiple passes with an ox-plow over the three to four month period prior to sowing (Tanner *et al.*, 1999). Heavy rainfall may occur during this period, leading to serious erosion. In recent years, a growing awareness of the importance of sustaining soil productivity has increased interest in soil and water conservation via conservation tillage based crop production systems (Lal, 1989). However, Scott (1969) reported that cultivation significantly reduced the number of white heads caused by take-all in wheat, and concluded that this was probably due to

enhanced microbial activity in the well-aerated mixture of soil and stubble. Moore & Cook (1984) reported that the best control of take-all in wheat was achieved by thorough tillage. They also suggested that early loosening of plowed soil hastened the decline of the take-all fungus relative to more compact soil under zero tillage. In addition, inoculum may be concentrated in the crown zone in ZT soil, whereas the inoculum in tilled soil is more diffusely distributed throughout the tillage zone. Cook & Waldher (1977) reported equal eyespot incidence for both an uncultivated mulch and mould-board plowed soil. Herrman & Wiese (1985) showed that eyespot incidence was highest in plowed plots, intermediate in MT plots, and the least common in ZT plots. In the current study, CT clearly reduced the incidence of take-all and was neutral in its effect on the level of eyespot disease. Thus, the adoption of CT practices for wheat production in Ethiopia will not be hindered by an adverse effect of CT on these two trash-borne diseases of wheat.

The reported effects of either retaining or burning crop stubble on the incidence of take-all and eyespot vary dramatically. In Australia, burning stubble prior to sowing did not affect the incidence of take-all in continuously-cropped ZT wheat (de Boer *et al.*, 1992), but reduced the level of take-all in wheat sown after lupins (Murray *et al.*, 1991). In the UK, burning stubble prior to cultivation did not affect the incidence of take-all compared with plowing under stubble (Slope *et al.*, 1970). In Australia, Kollmorgen *et al.* (1987) reported that stubble mulching effectively reduced the survival of take-all in buried straw. Eyespot was reported to be more prevalent where residues were either retained on the surface or incorporated in the soil (Murray *et al.*, 1991), but was also reported to have been unaffected by burning prior to plowing (Slope *et al.*, 1970). de Boer *et al.* (1993) reported the highest incidence of eyespot associated with stubble retention in continuously-cropped ZT wheat. Burning of wheat stubble, on the other hand, reduced the incidence of the disease in the uncultivated plots to negligible levels, but did not eliminate the disease (de Boer *et al.*, 1993). They also showed that conventional tillage combined with stubble burning resulted in eyespot levels as high as with direct sowing into stubble, presumably because cultivation brought previously-buried, infected crop debris to the surface. In the current study, stubble management had no apparent effect on the incidence of take-all. Full stubble retention increased eyespot incidence relative to partial removal of stubble. Thus, wheat production with full stubble retention, particularly under CT practices, may have an adverse effect on the level of eyespot disease of wheat in Ethiopia.

**Table 7.10. Mean eyespot incidence for each treatment from the combined analysis over years of measurements during 1994, 1996, 1997 and 1999 at Asasa and Kulumsa**

Crop management practice <sup>a</sup>			Disease score <sup>b</sup>			
			Ox-plow		Mechanized	
			Tillage	Sequence	Asasa	Kulumsa
Burn	Conv	F	2.40	2.63 B	3.06	2.75
Burn	Conv	W	3.13	3.77 A	2.65	2.28
Burn	CT	F	3.54	3.00 B	2.33	2.11
Burn	CT	W	3.57	2.77 B	2.27	2.15
Rem	Conv	F	3.43	3.26 AB	2.93	2.38
Rem	Conv	W	3.47	3.13 AB	2.58	1.73
Rem	CT	F	2.93	2.65 B	2.65	3.04
Rem	CT	W	3.24	2.80 B	2.85	2.66
Ret	Conv	F	-	-	3.13	3.31
Ret	Conv	W	-	-	3.14	2.79
Ret	CT	F	-	-	2.97	3.32
Ret	CT	W	-	-	2.96	2.52
Mean			3.21	3.00	2.79	2.59
C.V.(%)			37.9	27.5	39.5	43.0
LSD(0.05)			NS	0.686	NS	NS
F-test:	Stubble management (SM)		NS	NS	NS	NS
	Tillage (T)		NS	†	NS	NS
	SM x T		NS	NS	NS	NS
	Cropping sequence (CS)		NS	NS	NS	NS
	SM x CS		NS	NS	NS	NS
	T x CS		NS	NS	NS	NS
	SM x T x CS		NS	*	NS	NS

†, \* Statistically significant at  $0.1 < P < 0.05$  and  $0.01 < P < 0.05$ , respectively.

Values within a column followed by the same letter(s) are not different at the 5% level of the LSD test.

<sup>a</sup> Burn = Complete burn of crop stubble; Rem = Partial removal of crop stubble; Ret = Complete retention of crop stubble; Conv = Conventional tillage; CT = Conservation tillage; F = Faba bean rotation with wheat (1 year in 3); W = Continuous wheat.

<sup>b</sup> Transformed using the square root of (weighted percent severity score + 0.5).

Cropping sequences may influence the inoculum density of residue-borne pathogens (Sutton & Vyn, 1990). Production of wheat in sequence with non-host crops may suppress wheat pathogens by allowing more time for the organisms to decline in residues, by modifying the residue microclimate, or through other effects (Sutton & Vyn, 1990). de Boer *et al.* (1993) reported that rotation of wheat with leguminous crops reduced the level of inoculum of take-all and eyespot relative to continuously cropped wheat. In the current study, cropping sequence had no consistent effect on the incidence of eyespot, although, inclusion of faba bean in the wheat-based rotation dramatically reduced the incidence of take-all relative to continuous wheat. Thus, rotation with faba bean can be promoted as one component of an integrated approach to control take-all disease of wheat in Ethiopia.

**Table 7.11. Correlations among individual plot grain yields and take-all and eyespot scores<sup>a</sup> for the 16 data sets included in the study**

Data set			Number of observations	Grain yield with		Take-all with Eyespot
Location	Year	System <sup>b</sup>		Take-all	Eyespot	
Asasa	1994	Ox	24	-0.370†	-0.316	0.372†
Asasa	1994	Mech	36	-0.376*	0.117	-0.081
Asasa	1996	Ox	24	-0.134	0.307	0.182
Asasa	1996	Mech	36	0.175	0.412*	0.320†
Asasa	1997	Ox	24	0.013	-0.101	0.148
Asasa	1997	Mech	36	-0.025	0.074	0.398*
Asasa	1999	Ox	24	-0.229	-0.198	0.803***
Asasa	1999	Mech	36	-0.323†	0.027	0.796***
Kulumsa	1994	Ox	24	-0.181	-0.010	0.699***
Kulumsa	1994	Mech	36	0.248	0.285†	0.753***
Kulumsa	1996	Ox	24	-0.550**	-0.090	0.295
Kulumsa	1996	Mech	36	-0.559***	-0.161	0.191
Kulumsa	1997	Ox	24	-0.194	-0.190	0.466*
Kulumsa	1997	Mech	36	-0.135	0.439**	-0.295†
Kulumsa	1999	Ox	24	-0.012	0.019	0.815***
Kulumsa	1999	Mech	36	0.170	0.041	0.834***

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

<sup>a</sup> Disease scores transformed using the square root of (weighted percent severity score + 0.5).

<sup>b</sup> Ox = Ox-plow system; Mech = Mechanized system.

## 7.4 Conclusions

Crop management practices differed in their impact on root diseases of wheat. While a three years rotation consisting of consecutive crops of wheat following faba bean reduced

the incidence of take-all, but had little effect on eyespot incidence. Zero and minimum tillage dramatically decreased take-all incidence compared to conventional tillage, but had little effect on eyespot incidence. Stubble burning exhibited no consistent effect on the incidence of either disease. However, full stubble retention relative to partial removal of the stubble tended to increase eyespot incidence.

## CHAPTER 8

# DETERMINATION OF THE EFFECTS OF WHEAT STRAW ON WHEAT SEEDLING GROWTH AND DEVELOPMENT

### 8.1 Introduction

The retention of wheat crop residues on the soil surface with conservation tillage practices is common in many wheat growing areas of the world (Felton *et al.*, 1987). Residue retention reduces the severity of soil erosion and enhances water infiltration (Harte & Armstrong, 1983). However, detrimental aspects of residue retention, including increased incidence of stubble-borne diseases and difficulties in planting small grain crops (Felton *et al.*, 1987), often nullify the beneficial effects of conservation tillage.

Decomposition is the principal means of reducing wheat residues in conservation tillage systems since neither residue burning nor incorporation is practical. The rate of residue decomposition is influenced primarily by environmental and crop management factors (Tanaka, 1986), with secondary influences comprising species and cultivar effects (Smith & Peckenpaugh, 1986), the chemical nature of the residue (Knapp *et al.*, 1983), and the composition of the microbial flora (Magan & Lynch, 1986).

A number of studies in the U.S. indicate that retention of stubble on the soil surface decreases the rate of stubble decomposition (Douglas *et al.*, 1980; Tanaka, 1986). In conventional tillage systems, where stubble is incorporated in the soil profile, there is greater mechanical disruption of the stubble and more intimate soil-straw contact, both factors favouring decomposition of the wheat straw (Douglas *et al.*, 1980). In addition, secondary tillage is common in conventional tillage systems, and is likely to further accelerate the rate of stubble decomposition.

There is a paucity of information on the role of environmental factors affecting cereal straw decomposition and the changes in the chemical nature of the residue as it decomposes. Stott *et al.* (1986) demonstrated that straw decomposition accelerates with increasing soil temperature and water content.

Retention of crop residues on the soil surface, in contrast to incorporation by tillage or elimination by burning, has been shown in many studies to increase soil organic carbon and total nitrogen (Rasmussen & Collins, 1991). Organic matter accumulation in the soil is dependent upon the quality of the residue and its rate of decomposition. Soil and residue factors that affect the rate of decomposition include temperature, water content, aeration, pH, % C, % N, % lignin, residue particle size, and degree of burial in the soil (Parr & Papendick, 1978).

Tillage can play an important role in the redistribution of organic matter and plant nutrients within the soil profile. Under conservation tillage, the majority of the crop residues are maintained on the soil surface instead of being mixed throughout the soil profile. Under conventional tillage, plowing and secondary tillage increase the rate of organic matter decomposition since tillage increases microbial contact with the crop residue and thereby stimulates microbial activity. The enhanced supply of nutrients due to residue decomposition under conventional tillage is only apparent until readily available organic residue has been consumed, producing CO<sub>2</sub> and stabilised humic compounds.

On the other hand, adverse effects of stubble retention have been attributed to reduced seedling density (Fischer *et al.*, 1988), reduced soil temperature (Aston & Fischer, 1986), increased leaf and root disease incidence (Cook & Hoglund, 1991), and the effects of phytotoxic leachates from decaying stubble on germinating crop seed and emerged seedlings (Purvis, 1990). However, Kirkegaard *et al.* (1994) reported that stubble retention had no significant effect on seedling density, or on the concentration of mineral N in the soil during the early growth period. There was also no effect of retained stubble on the incidence of root diseases or the apparent carry-over of foliar diseases in the stubble.

## 8.2 Results and Discussion

The results from the pot trials, presented as the combined analyses of variance across the three runs (i.e., repetitions over time), are shown separately for the Kulumsa (Table 8.1) and Asasa (Table 8.2) soils. The mean values for each measured parameter of the wheat seedlings as affected by the levels of straw management, and the type and rate of straw are

listed in Tables 8.3 and 8.4 for the Kulumsa and Asasa soils, respectively.

Highly significant run effects were observed for all measured seedling parameters for the Kulumsa soil (Table 8.1) and for all parameters apart from total number of leaves (TL) for the Asasa soil (Table 8.2). The significant run effects reflect seedling responses to the different ambient climatic conditions experienced by the pot trials conducted over time in the Kulumsa lath-house.

Scrutiny of the differences between the control treatment (i.e., nil straw) and the mean of the 12 treatments receiving straw revealed a greater effect of straw application to the Asasa soil than to the Kulumsa soil. For the Kulumsa soil (Table 8.3), only the parameter T/P exhibited a significant difference between the control and the mean of the 12 straw treatments. For the Asasa soil, tillers/plant (T/P), above ground biomass (ABM), and root biomass (RBM) exhibited significant effects due to added straw. Regardless of soil source, for each seedling parameter for which significance was observed, added straw reduced the measured parameter value relative to the control treatment. Thus, the general effect of adding straw to each soil, averaged across straw management, type and rate levels, was to suppress the wheat seedling parameters.

### **8.2.1 Effect of straw management**

Analysis of the effects of straw management practices on wheat seedlings grown in the Kulumsa soil revealed that T/P, RBM and TL exhibited significant differences due to SM treatments (Table 8.1). For the Asasa soil, all of the measured seedling parameters exhibited highly significant effects of SM (Table 8.2).

In general, straw burning resulted in the highest values for each above-ground seedling parameter, approaching the level of the control treatment, while soil incorporation of straw resulted in the lowest values (Tables 8.3 and 8.4). The two major exceptions to this general observation were emerged seedlings (ES) and seedling height (HT) in the Asasa soil. For these two parameters, straw burning was equal to soil incorporation, and both were greater than surface retention. For T/P and TL for both soils and ABM for the Asasa soil, straw

**Table 8.1. Effect of wheat straw on wheat seedling growth and development in the lath house experiment using Kulumsa soil: ANOVA results across three runs**

	ES	T/P	HT	ABM	RBM	TL
Run (Ru)	***	***	***	***	***	**
Straw management (S)		**			†	***
Ru x S						†
Type of straw (T)		*		*	**	†
Ru x T		†				*
S x T						
Ru x S x T	**					†
Rate of straw (R)		*		*		
Ru x R			*			
S x R		†		*		
Ru x S x R			†			†
T x R						
Ru x T x R						
S x T x R						
Ru x S x T x R		*				
Mean	8.58	1.86	43.5	5.84	1.77	6.98
C.V. (%)	13.3	22.3	11.6	23.1	26.2	17.5

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively

ES = Number of emerged seedlings/pot; T/P = Number of tillers/plant;

HT = Plant height (cm); ABM = Above-ground biomass (g/pot);

RBM = Root biomass (g/pot); TL = Total number of leaves per plant.

**Table 8.2. Effect of wheat straw on wheat seedling growth and development in the lath house experiment using Asasa soil: ANOVA results across three runs**

	ES	T/P	HT	ABM	RBM	TL
Run (Ru)	***	**	***	**	***	
Straw management (S)	**	***	**	**	*	†
Ru x S		**	*	**	**	***
Type of straw (T)						
Ru x T						
S x T	*	†				†
Ru x S x T					*	
Rate of straw (R)		**	**	**		†
Ru x R						†
S x R		†		*	*	†
Ru x S x R				**		
T x R						
Ru x T x R						
S x T x R		*				
Ru x S x T x R						
Mean	8.21	1.82	41.3	4.89	1.57	7.32
C.V. (%)	15.6	24.0	10.0	27.4	33.3	22.5

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

ES = Number of emerged seedlings/pot; T/P = Number of tillers/plant;

HT = Plant height (cm); ABM = Above-ground biomass (g/pot);

RBM = Root biomass (g/pot); TL = Total number of leaves per plant.

**Table 8.3. Effect of wheat straw on wheat seedling growth and development in the lath house experiment using Kulumsa soil: treatment means across three runs.**

	ES	T/P	HT	ABM	RBM	TL
<b>Straw management</b>						
Burn	8.75	1.94A	44.2	5.99	1.77AB	7.53A
Incorporation	8.65	1.70B	43.3	5.55	1.67B	6.67B
Surface retention	8.33	1.93A	42.8	5.98	1.88A	6.73B
LSD(5%)		0.17			0.19	0.49
<b>Type of straw</b>						
Naturally degraded	8.64	1.95A	42.9	6.07A	1.89A	7.15
Fresh	8.51	1.77B	43.9	5.62B	1.65B	6.81
<b>Rate of straw</b>						
0.8 t/ha	8.68	1.94A	43.6	6.07A	1.78	7.09
2.5 t/ha	8.47	1.78B	43.3	5.62B	1.76	6.86
Control	8.5	2.20	42.8	6.4	1.8	8.3
Contrast	NS	*	NS	NS	NS	NS

Values followed by the same or no letter within a column for each straw factor are not significantly different at the 5% level of the LSD test.

ES = Number of emerged seedlings/pot; T/P = Number of tillers/plant;  
 HT = Plant height (cm); ABM = Above-ground biomass (g/pot);  
 RBM = Root biomass (g/pot); TL = Total number of leaves per plant;  
 Contrast = orthogonal contrast of control vs. 12 treatments receiving straw.

**Table 8.4. Effect of wheat straw on wheat seedling growth and development in the lath house experiment using Asasa soil: treatment means across three runs**

	ES	T/P	HT	ABM	RBM	TL
<b>Straw management</b>						
Burn	8.44A	1.95A	42.3A	5.44A	1.57AB	7.67A
Incorporation	8.48A	1.57B	42.0A	4.67B	1.41B	6.92B
Surface retention	7.71B	1.94A	39.5B	4.52B	1.73A	7.37AB
LSD(5%)	0.25	0.18	1.68	0.54	0.21	0.67
<b>Type of straw</b>						
Naturally degraded	8.28	1.21	41.0	4.89	1.60	7.31
Fresh	8.14	1.24	41.5	4.89	1.53	7.34
<b>Rate of straw</b>						
0.8 t/ha	8.31	1.92A	42.4A	5.24A	1.64	7.57
2.5 t/ha	8.11	1.73B	40.2B	4.55B	1.51	7.08
Control	8.6	2.3	41.5	7.30	2.20	8.5
Contrast	NS	**	NS	***	**	NS

Value followed by the same or no letter within a column for each straw factor are not significantly different at the 5% level of the LSD test.

ES = Number of emerged seedlings/pot; T/P = Number of tillers/plant;  
 HT = Plant height (cm); ABM = Above-ground biomass (g/pot);  
 RBM = Root biomass (g/pot); TL = Total number of leaves per plant;  
 Contrast = orthogonal contrast of control vs. 12 treatments receiving straw.

burning resulted in significantly higher values than soil incorporation of the straw. Surface retention of the straw was inconsistent in its effects because the T/P for surface retention of straw was equal to burn and higher than incorporation in both soils. The TL was intermediate to burn and incorporation in the Asasa soil, and was lower than burn and equal to incorporation in the Kulumsa soil. For both soils, RBM exhibited the highest values for surface retention and the lowest values for incorporation, while the burn treatment was intermediate and not different from the other two treatments. The general reduction of wheat seedling growth and development in the incorporation treatment may have been due to a nitrogen negative period or an allelopathic effect of wheat residue, since many crop residues, including wheat straw, contain allelopathic compounds (Guenzi and McCalla, 1966).

The significant interaction effects of run by straw management (Tables 8.1 and 8.2) were attributable primarily to the non-significance of SM effects in one or two of the three runs for the relevant seedling parameters (Table 8.9).

### 8.2.2 Effect of application rate

The main effect of the rate of straw application was quite consistent across seedling parameters and for both soils. In each case, 2.5 t/ha of straw depressed seedling parameter values relative to 0.8 t/ha (Tables 8.3 and 8.4). Run by rate interaction was only significant for HT on the Kulumsa soil and TL on the Asasa soil (Table 8.6), and in the second run only.

The interaction between straw management and rate of straw application was significant for two seedling parameters in the Kulumsa soil (Table 8.1) and four seedling parameters in the Asasa soil. Straw burning eliminated the negative effect of the highest straw application rate for T/P in both soils, and for ABM and RBM in the Asasa soil (Table 8.8). Surface retention of straw eliminated the suppression of seedling parameters due to the 2.5 t/ha application rate for ABM in both soils, and for T/P, RBM and TL in the Asasa soil. For each of the seedling parameters exhibiting an interaction of straw management by rate, incorporation of straw in the soil consistently resulted in a suppression of parameter values.

### 8.2.3 Effect of straw decomposition

Type of straw exhibited a significant effect upon T/P, ABM, RBM and TL for the Kulumsa soil (Table 8.1). In each case, naturally degraded straw exhibited higher values for the affected parameters relative to fresh straw (Table 8.3). Run by straw type interaction was significant for T/P and TL on the Kulumsa soil. In each case, the degraded straw resulted in higher parameter values than fresh straw in one run, while the other two runs exhibited no significant effect of straw type (Table 8.5). For the Asasa soil, there was no significant effect of straw type or run by type interaction for any of the measured seedling parameters (Table 8.2).

**Table 8.5. Effect of interaction of run by type of straw on wheat seedling growth and development in the lath house experiment using Kulumsa soil.**

Run	T/P		TL	
	ND	FR	ND	FR
1	1.51	1.55	6.58	6.27
2	1.82	1.61	8.58A	7.54B
3	2.51A	2.15B	6.28	6.62
LSD(5%)	0.24		0.70	

Values followed by the same or no letter within a row for each parameter are not significantly different at the 5% level of the LSD test.

T/P = Number of tillers/plant; TL = Total number of leaves per plant.

ND = Naturally degraded; FR = Fresh.

**Table 8.6. Effect of interaction of run by rate of straw (t/ha) on wheat seedling growth and development in the lath house experiment using Kulumsa soil and Asasa soil**

Run	Kulumsa soil		Asasa soil	
	HT	TL	HT	TL
	0.8	2.5	0.8	2.5
1	27.7	30.0	7.67	7.26
2	53.3A	50.0B	7.98A	6.73B
3	49.8	50.0	7.05	7.25
LSD(5%)	2.88		0.95	

Values followed by the same or no letter within a row for each parameter are not significantly different at the 5% level of the LSD test.

HT = Plant height (cm); TL = Total number of leaves per plant.

The interaction between straw type and straw management was only significant for ES and T/P on the Asasa soil (Table 8.7). For ES, there was no reduction in seedling emergence due to the application of fresh straw if the straw was either burned or incorporated in the soil. Thus, suppression of ES was only observed with surface retention of fresh straw (Table 8.7).

The interaction effect on T/P was less clear (Table 8.7). For degraded straw, burning was greater than incorporation and surface retention. For fresh straw, burning was greater than incorporation, while surface retention was intermediate and equal to the other two straw management practices. The interaction effect of straw type by straw rate was non-significant for all measured seedling parameters on both soils.

**Table 8.7. Effect of interaction of straw management by type of straw on wheat seedling growth and development in the lath house experiment using Asasa soil.**

Straw management	ES		T/P	
	ND	FR	ND	FR
Burn	8.38A	8.50A	2.17A	2.03AB
Incorporation	8.25A	8.71A	1.52D	1.65CD
Surface retention	8.21A	7.21B	1.74CD	1.82BC
LSD(5%)	0.73		0.25	

Values followed by the same letters within each parameter are not significantly different at the 5% level of the LSD test.

ES = Number of emerged seedlings/pot; T/P = Number of tillers/plant.

#### 8.2.4 Nutrient content of wheat seedlings

The ANOVA of the main effects of SM for the Kulumsa soil revealed that Ca, Mg, Cu, Zn, Mn, P and N contents of wheat seedlings were significantly affected by the treatments (Table 8.10). For the Asasa soil, Ca, Mg, K, Mn, P and N contents exhibited a significant difference among SM treatments (Table 8.10). Burning of the straw markedly increased the nutrient contents of wheat seedlings for each nutrient affected by SM (Table 8.11), while surface retention resulted in the lowest nutrient content levels. Soil incorporation of straw had an intermediate effect and was often equal to the other two straw treatments (Table 8.11). A previous study indicated that retention of stubble on the soil surface decreased the rate of stubble decomposition (Douglas *et al.*, 1980) and therefore also the rate of release of nutrients into the soil by mineralization.

The rate of straw application affected Ca and Mn contents of seedling on the Kulumsa soil and N content on the Asasa soil (Table 8.10). For each parameter exhibiting a significant effect, 0.8 t/ha resulted in a higher nutrient content of wheat seedlings cf. the 2.5 t/ha rate (Table 8.11). It has been reported that the concentration of soil organic matter depends on the quantity of residue retained and its rate of decomposition (Rasmussen & Collins, 1991).

**Table 8.8. Effect of interaction of straw management by rate of straw (t/ha) on wheat seedling growth and development in the lath house experiment using Kulumsa soil and Asasa soil.**

Straw management	Kulumsa soil				Asasa soil							
	T/P		ABM		T/P		ABM		RBM		TL	
	0.8	2.5	0.8	2.5	0.8	2.5	0.8	2.5	0.8	2.5	0.8	2.5
Burn	1.91AB	1.97AB	5.83A	6.15A	2.03A	1.88AB	6.07A	4.81BC	1.70AB	1.45BC	8.16A	7.18BC
Incorporation	1.83B	1.58C	6.16A	4.95B	1.78B	1.36C	5.20B	4.14C	1.58AB	1.23C	7.63AB	6.48C
Surface retention	2.07A	1.80BC	6.20A	5.76A	1.94AB	1.94AB	4.45C	4.69BC	1.62AB	1.85A	7.18BC	7.57AB
LSD(5%)	0.24		0.77		0.25		0.77		0.30		0.94	

Values followed by the same letters within each parameter are not significantly different at the 5% level of the LSD test.

T/P = Number of tillers/plant; ABM = Above-ground biomass (g/pot); RBM = Root biomass (g/pot); TL = Total number of leaves per plant.

**Table 8.9. Effect of interaction of run by straw management on wheat seedling growth and development in the lath house experiment using Kulumsa soil and Asasa soil.**

SM	Kulumsa soil						Asasa soil											
	TL			T/P			HT			ABM			RBM			TL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Burn	7.19A	8.76A	6.64	2.37A	1.72	1.77	28.3	48.0A	50.3A	4.41A	5.05	6.86A	2.74A	1.21B	0.77	7.94A	7.84	7.24
Incorporation	5.62B	7.73B	6.66	1.54B	1.49	1.67	27.3	48.9A	48.8A	2.99B	4.66	6.35A	2.09B	1.23B	0.91	5.93B	7.44	7.38
SR	6.45AB	7.69B	6.06	2.39A	1.54	1.89	28.7	44.8B	45.0B	4.22A	4.40	5.09B	2.79A	1.67A	0.74	8.52A	6.77	6.83
LSD(5%)	0.85			0.31			2.90			0.94			0.37			1.16		

Values followed by the same or no letters within a column for each parameter are not significantly different at the 5% level of the LSD test.

T/P = Number of tillers/plant; HT = Plant height (cm); ABM = Above-ground biomass (g/pot); RBM = Root biomass (g/pot); TL = Total number of leaves per plant.

SR = Surface retention; SM = Straw management.

Table 8.10. Effect of straw treatments on wheat seedling nutrient content in the lath house experiment using Kulumsa and Asasa soils: ANOVA results.

	Kulumsa										Asasa									
	Ca (%)	Mg (%)	K (%)	Na (ppm)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	P (%)	N (%)	Ca (%)	Mg (%)	K (%)	Na (ppm)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	P (%)	N (%)
S	***	**			***	†	***	***	*	*	***	**	***				†	**	***	***
T				†	*												*	†		*
S x T												†								***
R	**		†		†			**	†	†	†									***
S x R	*	*	*	*	***		**	*		**				*						
T x R																				
S x T x R				†							†		*						†	*
Mean	0.41	0.13	5.56	378	4.36	592	24.3	79.9	0.38	4.06	0.37	0.14	4.42	312	3.83	391	21.8	62.4	0.43	3.45
C.V.(%)	10.1	23.8	13.3	19.6	13.5	93.5	11.8	17.8	10.6	9.98	18.5	35.7	19.7	27.1	49.4	52.8	30.4	24.7	15.0	10.2

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

S = Straw management; T = Type of straw; R = Rate of straw.

**Table 8.11. Effect of straw treatments on wheat seedling nutrient content in the lath house experiment using Kulumsa and Asasa soils: treatment means**

	Kulumsa										Asasa										
	Ca (%)	Mg (%)	K (%)	Na (ppm)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	P (%)	N (%)	Ca (%)	Mg (%)	K (%)	Na (ppm)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	P (%)	N (%)	
SM																					
Burn	0.44A	0.15A	5.78	355	4.8A	653AB	27A	94A	0.39A	4.30A	0.42A	0.16A	5.22A	321	4.31	407	24A	73A	0.49A	3.91A	
Incorp.	0.42A	0.14A	5.64	404	4.7A	776A	26A	85A	0.38AB	4.03AB	0.39A	0.16A	4.35B	334	3.81	463	23AB	59B	0.43B	3.60B	
Surface	0.37B	0.11B	5.25	374	3.6B	346B	20B	62B	0.35B	3.86B	0.31B	0.10B	3.69C	282	3.35	303	19B	56B	0.37C	2.85C	
LSD(5%)	0.032	0.023	----	----	0.42	398	2.1	10.2	0.032	0.29	0.031	0.039	0.63	----	----	----	4.76	11.1	0.05	0.25	
Type																					
ND	0.41	0.14	5.66	358	4.2B	525	24	77	0.37	4.08	0.36	0.13	4.35	300	3.82	348	20B	58	0.42	3.32B	
FR	0.41	0.13	5.45	398	4.6A	659	25	82	0.38	4.08	0.39	0.15	4.48	324	3.83	434	24A	66	0.43	3.58A	
Rate																					
0.8 t/ha	0.44A	0.14	5.74	376	4.5	618	25	86A	0.39	4.16	0.39	0.14	4.61	299	4.23	392	21.5	62.9	0.43	3.66A	
2.5 t/ha	0.39B	0.13	5.37	380	4.2	565	24	74B	0.36	3.96	0.35	0.14	4.22	325	3.42	390	22.0	61.9	0.43	3.25B	
Control	0.43	0.17	5.0	311	3.88	382	25.5	90.0	0.36	4.21	0.45	0.17	5.43	282	5.38	610	22.8	76.9	0.44	3.89	
Contrast	***	*	NS	*	***	NS	***	***	†	**	**	*	**	NS	NS	NS	NS	*	**	***	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

Values within a column for each straw treatment factor followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SM = Straw management; Incorp. = Incorporation; Surface = Surface retention; Type = Type of straw; ND = Naturally degraded; FR = Fresh; Rate = Rate of straw.

The type of straw showed a significant effect on Cu content for the Kulumsa soil, and for Zn and N for the Asasa soil (Table 8.11). For both soil types, fresh straw significantly increased the contents of those elements affected by the type of straw (Table 8.11).

The orthogonal contrast comparing the nutrient content of the control vs. the other 12 treatments receiving straw exhibited significance for most of the nutrients except K and Fe for the Kulumsa soil. For the Asasa soil, a significant difference was observed for six parameters out of 10 (Table 8.11). For most of the nutrients for both soil types, the mean value of the surface retention treatment was lower than the mean value of the control plot (Table 8.11).

The interaction of SM by rate of straw reflected significance for the Kulumsa soil on Mg, K, Cu, Fe, Zn, Na and N contents (Table 8.12). A significantly lower content was observed for most nutrients for the Kulumsa soil for the combination of surface retention with 2.5 t/ha of straw, with minimal differences among the other treatment combinations. The major exception was observed for Na in which the lowest content resulted from the combination of straw burning with 2.5 t/ha of straw. In general, the low nutrient content due to the combination of surface retention and the highest rate of straw reflected the immobilisation of nutrients due to the slow rate of straw decomposition.

Similarly, the interaction effect of SM by rate of straw on Na content for the Asasa soil showed that the lowest content was obtained with the combination of surface retention and the 2.5 t/ha application rate (Table 8.13).

The interaction effect of SM by type of straw was significant for N content on the Asasa soil (Table 8.14). There was no difference due to straw type within the burn and incorporation SM treatments, however, within the surface retention treatment, naturally degraded straw resulted in a lower N content cf. fresh straw. The overall lowest N content was observed for the combination of surface retention with naturally degraded straw (Table 8.14).

**Table 8.12. Effect of interaction of straw management by rate of straw (t/ha) on the nutrient content of wheat seedlings in the lath house experiment using Kulumsa soil.**

Rate	Mg (%)		K (%)		Cu (ppm)		Na (ppm)		Ca (%)		Zn (ppm)		Mn (ppm)		N (%)	
	0.8	2.5	0.8	2.5	0.8	2.5	0.8	2.5	0.8	2.5	0.8	2.5	0.8	2.5	0.8	2.5
SM																
Burn	0.14A	0.15A	5.81A	5.76A	4.94AB	4.56ABC	395AB	316C	0.45A	0.43A	26.2AB	27.9A	97.5A	89.4AB	4.27A	4.33A
Incorporation	0.14A	0.14A	5.55A	5.72A	4.35BC	5.06A	377ABC	430A	0.44A	0.41A	24.9BC	26.4AB	85.5AB	84.0AB	3.94A	4.12A
Surface retention	0.13A	0.09B	5.87A	4.63B	4.27C	2.98D	354BC	394AB	0.42A	0.32B	22.9C	17.4D	75.1B	48.0C	4.28A	3.45B
LSD(5%)	0.032		0.75		0.60		75.2		0.045		2.92		14.5		0.41	

Values followed by the same letter within each parameter are not significantly different at the 5% level of the LSD test.

SM = Straw management.

**Table 8.13. Effect of interaction of straw management by rate of straw (t/ha) on Na (ppm) content of wheat seedlings in the lath house experiment using Asasa soil.**

SM	Rate of straw (t/ha)	
	0.8	2.5
Burn	264BC	378A
Incorporation	321ABC	347AB
Surface retention	312ABC	251C
LSD(5%)	88.6	

Values followed by the same letter(s) are not significantly different at the 5% level of the LSD test.

SM = Straw management.

**Table 8.14. Effect of interaction of straw management by type of straw on N (%) content of wheat seedlings in the lath house experiment using Asasa soil**

SM	Type of straw	
	Naturally degraded	Fresh
Burn	4.08A	3.74AB
Incorporation	3.44BC	3.76AB
Surface retention	2.47D	3.24C
LSD(5%)	0.36	

Values followed by the same letter(s) are not significantly different at the 5% level of the LSD test.  
SM = Straw management.

### 8.3. Conclusions

Straw application, in general, exhibited a negative effect upon most of the measured seedling parameters. The nil straw treatment (i.e., the control) exhibited higher values for measured seedling parameters than the mean of the 12 straw application treatments. Burning of the straw at least partially alleviated the negative effects of straw application. Conversely, soil incorporation of straw resulted in the most pronounced decrease in seedling parameters. Similarly, the highest rate of straw application consistently reduced seedling parameters, while the application of fresh straw reduced the measured parameters more than naturally degraded straw. The deleterious effects of the high rate of straw application were consistently exacerbated by soil incorporation, while straw burning (and occasionally surface retention) tended to negate the effects of the high straw application rate.

## CHAPTER 9

### PARTIAL BUDGET ANALYSIS

#### 9.1 Introduction

Ethiopia is characterised as having an agricultural driven economy although the agricultural sector is backward and low in productivity. The bulk of the national agricultural output comes from smallholders concentrated mainly in the highlands. In fact, the highlands contain the most important agro-ecological zones of the country in which the majority of crop and livestock production activities are concentrated (Gryseels, 1988). In spite of the existence of a high potential, agricultural production has not been able to cope with the national demand for food. As a result, the country has been unable to feed the fast growing population, and cannot provide the necessary raw materials for local agro-processing industries. The reasons for the low productivity of the agricultural sector are many, but limited use of modern inputs, natural phenomena such as drought, ecological degradation, and suboptimal and biased agricultural policies are among the main factors.

Changing the production frontier (i.e., by introducing modern varieties and inputs and other technological changes) can increase agricultural output. Formulating and implementing appropriate policies favourable to agricultural development, diffusing modern technology, and developing infrastructure will also promote agricultural development and raise output levels. Careful selection of appropriate and sustainable crop management systems will minimise the trade-off between maintaining profitability and reducing environmental impact. Crop management practices such as residue retention, minimum tillage, and crop rotation can reduce the agricultural sector's dependence on external inputs by enhancing internal nutrient recycling and maintaining long-term productivity by breaking weed and disease cycles.

Profitability is a function of production costs, output prices and yields. Cropping system components and characteristics impact on production costs and output yields, requiring the use of a common index for the measure of farmers' returns. In addition to profitability, income variability is a major consideration of risk-averse farmers. Income variability is a function of yield and the price variability of both outputs and inputs. A change in a

cropping system component can, therefore, affect income variability as driven by variation in crop yields.

Several short-term studies in the Ethiopian highlands examined the beneficial effects of break crops on wheat production. In one study, a faba bean break crop increased wheat yield by 69% cf. the yield of second year continuous wheat (Hailu *et al.*, 1989). In a second study, faba bean increased wheat yield by 44% cf. the yield of continuous wheat (Asefa *et al.*, 1992). However, no previous studies considered the long-term effects of cropping sequence, tillage practice, and straw management on cropping system profitability in the major Ethiopian agro-ecologies.

The results of multi-year, multi-location cropping system trials must be subjected to economic analysis prior to issuing recommendations to farmers. While some sustainable cropping practices lead to greater short-term profitability and are more readily adopted by and promoted among farmers, other production practices may carry short-term costs in order to achieve greater sustainability and profitability in the long-term (Tanner, 1997). Therefore, this study was initiated to examine the effects of integrated crop management practices on cropping system profitability in order to generate recommendations for Ethiopian farmers.

## 9.2 Results and Discussion

The results of the partial budget analysis of the four individual trials are presented in Tables 9.1 to 9.4.

Within each table, treatments are ranked from top to bottom in order of increasing "total costs that vary" (TCV). Several general trends are apparent in the cost components of the treatments included in the four trials. Firstly, conventional tillage costs less than the reduced tillage practices at Kulumsa (Tables 9.1 and 9.3), while the opposite was true at Asasa (Tables 9.2 and 9.4). Fallow season weed growth at Kulumsa greatly exceeded that at Asasa, due to a higher level of short-season rainfall in the Kulumsa environment. This necessitated more frequent application of glyphosate herbicide for fallow season weed control at Kulumsa relative to Asasa (Appendices 9.1 and 9.2), and markedly increased the cost of fallow season weed control for the minimum and zero tillage systems at Kulumsa.

Table 9.1. Results of the partial budget analysis of grain and straw yield data for the Kulumsa mechanised trial (1992-2000).

SM	Tillage	CS	Tr. #	TCV (EB/ha)	Grain + Straw			Grain only		
					NB (EB/ha)	MRR (%)	IV (%)	NB (EB/ha)	MRR (%)	IV (%)
Ret	Conv	Faba	9	1426	1957	--	54.0	1633	--	58.3
Burn	Conv	Faba	1	1444	2625	3817	71.1	2290	3752	73.7
Ret	Conv	CW	10	1464	2657	161	67.2	2217	D	76.0
Ret	Zero	Faba	11	1473	2434	D	88.0	2070	D	93.3
Burn	Conv	CW	2	1482	2953	1687	56.0	2468	475	63.1
Burn	Zero	Faba	3	1490	2420	D	75.3	2092	D	78.7
Ret	Zero	CW	12	1510	2122	D	87.5	1708	D	100.7
Parm	Conv	Faba	5	1526	2730	D	69.3	2225	D	73.8
Burn	Zero	CW	4	1528	2659	D	58.0	2206	D	66.9
Parm	Conv	CW	6	1564	2887	D	59.8	2249	D	69.9
Parm	Zero	Faba	7	1573	2544	D	83.6	2066	D	88.6
Parm	Zero	CW	8	1610	2103	D	91.5	1523	D	115.8

SM = straw management; CS = cropping sequence; TCV = total costs that vary; NB = net benefit; MRR = marginal rate of return; IV = index of variability of NB; Ret = complete retention of straw; Burn = straw burning; Parm = partial removal of straw; Conv = conventional tillage; Zero = zero tillage; Faba = crop rotation with one season of faba bean followed by two seasons of wheat; CW = continuous wheat; D = dominated.

Table 9.2. Results of the partial budget analysis of grain and straw yield data for the Asasa mechanised trial (1992-2000)

SM	Tillage	CS	Tr. #	TCV (EB/ha)	Grain + Straw			Grain only		
					NB (EB/ha)	MRR (%)	IV (%)	NB (EB/ha)	MRR (%)	IV (%)
Ret	Min	Faba	11	1258	1896	--	75.6	1611	--	81.1
Ret	Min	CW	12	1270	1430	D	67.3	1042	D	83.2
Burn	Min	Faba	3	1275	1832	D	82.3	1532	D	88.3
Burn	Min	CW	4	1287	1874	D	51.0	1445	D	61.7
Ret	Conv	Faba	9	1326	1870	D	78.0	1530	D	84.6
Ret	Conv	CW	10	1337	1905	11	32.3	1448	D	42.9
Burn	Conv	Faba	1	1343	2043	171 <sup>a</sup>	80.8	1703	109	86.4
Burn	Conv	CW	2	1355	2014	D	59.1	1572	D	72.0
Parm	Min	Faba	7	1358	1794	D	89.5	1347	D	103.4
Parm	Min	CW	8	1370	1358	D	65.0	845	D	88.8
Parm	Conv	Faba	5	1426	1940	D	80.9	1528	D	90.8
Parm	Conv	CW	6	1437	1875	D	60.0	1238	D	80.3

SM = straw management; CS = cropping sequence; TCV = total costs that vary; NB = net benefit; MRR = marginal rate of return; IV = index of variability of NB; Ret = complete retention of straw; Burn = straw burning; Parm = partial removal of straw; Conv = conventional tillage; Min = minimum tillage; Faba = crop rotation with one season of faba bean followed by two seasons of wheat; CW = continuous wheat; D = dominated.

<sup>a</sup> Calculated relative to T11, since the MRR associated with T10 was <100%.

Secondly, SM costs were clearly reflected in the ranking of treatments by TCV for all of the trials. For the mechanised trials (Tables 9.1 and 9.2), treatments including full straw retention tended to exhibit the lowest TCVs, those with straw burning were intermediate, and those including partial straw removal had the highest TCVs. For the ox-plow trials (Tables 9.3 and 9.4), treatments including straw burning tended to exhibit lower TCVs relative to those including partial straw removal.

Thirdly, across all trials, treatments including rotation with faba bean exhibited lower variable costs than those including continuous wheat. Although the faba bean crop incurred higher costs for seed, hand weeding and threshing relative to wheat, these higher costs were more than offset by the lower fertilizer rates, particularly for N, applied to faba bean.

For the Kulumsa mechanised trial (Table 9.1), the lowest cost treatment (T9) combined full stubble retention + conventional tillage + faba bean rotation. Considering net benefits, only three of the 11 higher-cost treatments were non-dominated in the analysis based on grain and straw market values, while only two treatments were non-dominated in the analysis based solely on grain market values. In both analyses, stubble burning + conventional tillage + faba bean rotation (T1) was extremely profitable relative to the lowest-cost treatment (T9), reflecting the major beneficial impact that burning had upon wheat grain yield. However, also in both analyses, the economic optimum treatment (T2) combined stubble burning + conventional tillage + continuous wheat. Faba bean yields in the Kulumsa mechanised trial (mean 2240 kg/ha) were markedly lower than continuous wheat yields (mean 3084 kg/ha), and wheat also commanded a slightly higher market price than faba bean. The combination of these two factors more than offset the yield advantage for wheat in rotation with faba bean relative to continuous wheat (ca. 432 kg/ha in this trial). T2 was particularly profitable relative to T1 when straw market value was included in the partial budget analysis, since faba bean straw has no economic value at present in Ethiopia.

For the Asasa mechanised trial (Table 9.2), the lowest cost treatment (T11) combined full stubble retention + minimum tillage + faba bean rotation. Considering net benefits, only T1 among the 11 higher-cost treatments was non-dominated, regardless of whether the market value of straw was included in the partial budget analysis. Thus, the economic

Table 9.3. Results of the partial budget analysis of grain and straw yield data for the Kulumsa ox-plow trial (1992-2000).

SM	Tillage	CS	Tr. #	TCV (EB/ha)	Grain + Straw			Grain-only		
					NB (EB/ha)	MRR (%)	IV (%)	NB (EB/ha)	MRR (%)	IV (%)
Burn	Conv	Faba	1	1390	2905	--	64.4	2539	--	66.0
Burn	Conv	CW	2	1418	3316	1437	55.4	2830	1019	62.3
Parm	Conv	Faba	5	1472	2726	D	66.6	2220	D	71.1
Burn	Min	Faba	3	1489	2877	D	60.5	2530	D	62.1
Parm	Conv	CW	6	1501	3178	D	55.4	2434	D	66.1
Burn	Min	CW	4	1517	2935	D	54.2	2470	D	61.7
Parm	Min	Faba	7	1571	2658	D	72.4	2174	D	76.3
Parm	Min	CW	8	1598	2749	D	66.7	2116	D	79.7

SM = straw management; CS = cropping sequence; TCV = total costs that vary; NB = net benefit; MRR = marginal rate of return; IV = index of variability of NB; Burn = straw burning; Parm = partial removal of straw; Conv = conventional tillage; Min = minimum tillage; Faba = crop rotation with one season of faba bean followed by two seasons of wheat; CW = continuous wheat; D = dominated.

Table 9.4. Results of the partial budget analysis of grain and straw yield data for the Asasa ox-plov trial (1992-2000)

SM	Tillage	CS	Tr. #	TCV (EB/ha)	Grain + Straw			Grain only		
					NB (EB/ha)	MRR (%)	IV (%)	NB (EB/ha)	MRR (%)	IV (%)
Burn	Min	Faba	3	1330	2128	--	65.2	1760	--	69.6
Burn	Min	CW	4	1352	2146	84	36.7	1718	D	44.0
Parm	Min	Faba	7	1413	2012	D	66.4	1561	D	77.4
Parm	Min	CW	8	1433	1575	D	47.5	1034	D	66.4
Burn	Conv	Faba	1	1513	2157	7	58.2	1802	23	62.8
Burn	Conv	CW	2	1535	2106	D	40.7	1617	D	51.3
Parm	Conv	Faba	5	1596	1631	D	71.9	1176	D	81.9
Parm	Conv	CW	6	1617	1561	D	53.4	1021	D	74.4

SM = straw management; CS = cropping sequence; TCV = total costs that vary; NB = net benefit; MRR = marginal rate of return; IV = index of variability of NB; Burn = straw burning; Parm = partial removal of straw; Conv = conventional tillage; Min = minimum tillage; Faba = crop rotation with one season of faba bean followed by two seasons of wheat; CW = continuous wheat; D = dominated.

optimum treatment in this trial (T1) combined straw burning + conventional tillage + faba bean rotation, reflecting the yield-enhancing effect of each of these factors acting independently. In contrast to the situation at Kulumsa, faba bean yields in the Asasa mechanised trial (mean 2194 kg/ha) were closer to continuous wheat yields (mean 2508 kg/ha), and the yield advantage for wheat in rotation with faba bean relative to continuous wheat was greater in this trial (ca. 612 kg/ha). Eliminating the market value of straw slightly reduced the profitability of T1 vis-à-vis T11.

For the Kulumsa ox-plow trial (Table 9.3), the lowest cost treatment (T1) combined stubble burning + conventional tillage + faba bean rotation. Considering net benefits, only T2 among the seven higher-cost treatments was non-dominated regardless of whether the market value of straw was included in the partial budget analysis. Thus, the economic optimum treatment (T2) for the Kulumsa ox-plow trial combined straw burning + conventional tillage + continuous wheat. This same treatment combination was also economically optimal for the Kulumsa mechanised trial. Faba bean yields in the Kulumsa ox-plow trial (mean 2446 kg/ha) were more than 1.0 t/ha lower than continuous wheat yields (mean 3497 kg/ha), and wheat commanded a higher market price than faba bean. These two factors combined more than offset the yield advantage for wheat in rotation with faba bean relative to continuous wheat (ca. 302 kg/ha in this trial). T2 was highly profitable relative to T1 regardless of whether straw market value was included in the partial budget analysis.

For the Asasa ox-plow trial (Table 9.4), the lowest cost treatment (T3) combined stubble burning + minimum tillage + faba bean rotation. Considering net benefits, only T4 and T1 among the seven higher-cost treatments were non-dominated. Both treatments exhibited a low MRR (i.e., <100%) relative to T3, and it is questionable whether such a low rate of return would warrant recommendation of T4 or T1 to the farming community. Thus, in the absence of a more profitable treatment, T3, the lowest-cost treatment, is the economically optimal treatment to recommend to farmer, thus burning + minimum tillage + faba bean rotation (CIMMYT, 1988). In the Asasa ox-plow trial, faba bean yields (mean 2564 kg/ha) were quite similar to continuous wheat yields (mean 2582 kg/ha), and the yield advantage for wheat in rotation with faba bean relative to continuous wheat (ca. 608 kg/ha) was similar to the high level observed in the Asasa mechanised trial.

In each of the four trials, the index of variability (IV) of net benefit did not vary markedly between the lowest-cost and the economic optimum treatments (Tables 9.1 to 9.4). Thus, stability of farm level income would not be markedly affected by adoption of the economic optimum cropping practices in each zone and production system.

### 9.3 Conclusions

Treatments combining faba bean rotation + stubble burning were the lowest cost options for the ox-plow production systems, while treatments combining faba bean rotation + full stubble retention were the lowest cost options for the mechanised production systems. In the Kulumsa agro-ecological zone, conventional tillage was lower cost vis-à-vis zero and minimum tillage in the mechanised and ox-plow system trials, respectively. However, due to a markedly lower cost of fallow season weed control, minimum tillage was lower cost vis-à-vis conventional tillage in the Asasa agro-ecological zone.

Economic optimum treatments for each trial generally reflected the trade-off between:

- 1) the yield differential between faba bean and continuous wheat in each specific location and product system versus
- 2) the yield advantage for wheat in rotation with faba bean relative to continuous wheat.

In the Kulumsa agro-ecological zone, the yield of faba bean was much lower than the yield of continuous wheat (i.e., the differential ranged from 844 to 1051 kg/ha), and the yield advantage for wheat in rotation with faba bean was relatively low (i.e., ranging from 302 to 432 kg/ha). Thus, the economic optimum practice for both the mechanised and ox-plow production systems at Kulumsa combined stubble burning + conventional tillage + continuous wheat.

By contrast, in the Asasa agro-ecological zone, faba bean was more profitable than continuous wheat in both production systems. For the Asasa mechanised trial, the economic optimum practice combined stubble burning + conventional tillage + faba bean rotation. For the Asasa ox-plow trial, the lowest cost treatment was economically optimal, combining stubble burning + minimum tillage + faba bean rotation.

## CHAPTER 10

### GENERAL DISCUSSION AND CONCLUSIONS

This study showed that crop management systems need to be maintained and studied over a long time to assess their ability to sustain production. The time period must be long enough to cover the expected climatic variation, to allow for growing conditions to develop characteristics of the system. These characteristics will be dynamic and will change according to the prevailing weather conditions of the particular year. This study covered the years 1992 to 2000, which included large variations in climatic conditions. The results that will be discussed were obtained from two sites, Kulumsa and Asasa. At each site a mechanised and ox-plow trial was conducted, thus four trials each year for 9 years, giving a total of 36 trials. The Treatments were:

Each mechanised trial consisted of 12 treatments comprising the complete factorial combinations of:

- a) three levels of post-harvest straw management (SM) (i.e., burning of stubble, partial (>50%) removal of stubble, and complete retention of stubble);
- b) two levels of tillage (i.e., zero tillage (ZT) at Kulumsa and minimum tillage (MT) at Asasa vs. conventional tillage (CT) at each site), and;
- c) two levels of cropping sequence (CS) (i.e., continuous bread wheat vs. a rotation of one year of faba bean (*Vicia faba*) followed by two years of bread wheat).

The ox-plow trials omitted complete stubble retention as a SM treatment. Thus, each ox-plow trial consisted of eight treatments comprising the complete factorial combination of:

1. two levels of post-harvest SM (i.e., burning of stubble, and partial (>50%) removal of stubble);
2. two levels of tillage (i.e., MT vs. conventional tillage) and;
3. two levels of CS (i.e., continuous bread wheat vs. a rotation of one year of faba bean followed by two years of wheat).

**Grain Yield:**

The grain yield response to straw management (SM) practices was by and large consistent. Thus, the burning of straw (BURN) treatment was consistently superior to the partial removal of the straw by grazing (PARM) in seven years in the ox-plow trial. In the 11 instances showing SM effects in the mechanised trials, BURN was superior to one or both of the PARM and straw retention (RET) treatments in eight cases. Many reports reflect an immediate yield advantage due to stubble burning, but others indicate inconsistent effects of burning on cereals grain yield (Rasmussen & Rohde, 1988). Burning crop stubble still resulted in slightly higher yields towards the end of the experiment. Heenan *et al.* (1994) stated that burning crop stubble resulted in slightly higher yields than retaining the stubble, in a long-term trial in Australia. However, in this study reductions in yield with straw retention occurred in years when wet conditions prevailed early in the season.

Response of crop grain yields to tillage varied slightly across years, perhaps in response to prevailing weather conditions during certain growing seasons. Conventional tillage (CT) outyielded zero tillage (ZT) or minimum tillage (MT) in the mechanised trials with the exception of two trials in 1997 and one trial in 2000. Thus, in the current study, the tillage effect on grain yield was more pronounced across years than the SM effect. However, yield advantages were obtained from ZT or MT only for three trials. Thus, response of wheat yield to tillage methods varied with the prevailing weather conditions in the particular growing season.

Cropping sequence (CS) significantly affected wheat grain yield at both the Kulumsa and Asasa locations and for both the mechanised and ox-plow system trials. In each of the 17 instances where CS affected wheat grain yields, the first or second year wheat following faba bean in the rotation treatments were superior to continuous wheat (CW). The effect of CS was non-significant in only seven of the 24 trial and season combinations in which the CS effect on wheat grain yield could be measured. The use of legumes in sequential cropping with wheat can result in several benefits to sustain crop production (Higgs *et al.*, 1990). In Ethiopia, a number of cropping sequence trials have confirmed the importance of including dicots, particularly legumes, in the cropping system to improve yield and sustain

production (Amanuel & Tanner, 1991). The results from this study have also proven the advantages of including legumes in the wheat cropping systems of Ethiopia, a practice that should be recommended.

#### *Nitrogen concentration and uptake:*

Straw management (SM) significantly affected wheat N uptake at both locations and systems trials. BURN significantly increased wheat N uptake compared to PARM and RET. Thus, stubble burning results in a higher early season availability of N, which stimulates vegetative growth. Nitrogen taken up after anthesis is generally translocated directly to the grain (Rasmussen & Rohde, 1988).

The grain nitrogen concentration of the wheat following faba bean tended to be higher than that of continuous wheat. The amount of N partitioned to the grain from the vegetative portion is a major factor affecting the grain protein concentration. The higher amount of N partitioned to the grain of wheat following faba beans, compared with continuous wheat, was probably due to increased soil and plant N (Bailey, 1982). It could also be due to a large continuous supply of N to the wheat crop through decomposition of the legume residues (Baldock *et al.*, 1981) and other beneficial effects of crop rotation (Crookston *et al.*, 1988). Thus, inclusion of grain legumes in cropping sequences generally increases soil nitrate, grain yield, total N accumulation and N-use efficiency of the subsequent wheat crop, compared with continuous wheat.

Across the trials and years, CT increased the N content and uptake of wheat relative to ZT or MT, probably due to better aeration and mineralization. Christensen *et al.* (1994), state that wheat response to N fertiliser can vary with tillage system and soil water status. Rao & Dao (1992) suggest that cereals under reduced tillage and zero tillage may require additional N fertiliser to reach production levels similar to conventional tillage because of lower root extraction efficiencies or N availability.

*Soil penetrometer resistance:*

The year or seasonal effect on soil penetrometer resistance (PR) was highly significant for four trials. The first PR measurements that were taken were the lowest viz. the 1994 data for the Kulumsa trials and the 1996 data for the Asasa trials. PR measurements recorded later namely during 1999, were higher, suggesting a trend for PR to increase over seasons, even though, the main effect SM did not significantly affect PR in any of the four trials.

SM by year interaction was significant in two of the trials. In the Asasa mechanised trial, stubble burning exhibited a significantly lower PR than either partial removal or complete retention in 1996. In 1998 the burn and retention treatments had lower PR values than partial removal and in 1999 retention was associated with lower PR values than stubble burning, while partial removal was intermediate and not significantly different from either. The season why, the association of higher PR values with complete stubble retention in 1996 contradicts previous findings showing favourable effects of surface residues on reducing soil crust strength and the bulk density of the surface soil layer under conservation tillage (Unger & Fulton 1990), is unclear.

Tillage practices significantly affected soil PR in both the mechanised trials and ox-plow trials where PR was consistently higher under conservation tillage. Ehlers *et al.* (1983) also state that when soils are placed under zero tillage management the surface layer may become more compacted than under conventional tillage particularly in coarse textured soils. Other studies conducted in various parts of the world have also demonstrated increases in PR for conservation tillage (Unger, 1996, Sweeney & Mayer, 1995). However, there were not consistently associated with reductions in wheat grain yield (Unger & Fulton, 1990).

CS did not have a significant effect on soil PR in any of the four trials. However, Chan & Heenan (1996) reported significant effects of CS on soil PR, particularly in rotations of cereals with dicotyledonous crops versus cereals dominated rotation, while McFarland *et al.* (1990) did not observe differences in soil PR related to CS.

**Soil pH:**

In the Kulumsa ox-plow trial PARM showed an increased in pH with soil depth. MT significantly increased soil pH in the Asasa mechanised trial during 1999. It has been reported that soil organic matter accumulation under no tillage management help to alleviate problems associated with low soil pH (Hargrove & Thomas, 1981).

**Soil nitrogen:**

Tillage significantly affected soil NO<sub>3</sub> only in the Asasa mechanised trial during 1998, where MT reduced the soil NO<sub>3</sub> content cf. conventional tillage. Contrasting results were found by Thomas *et al.* (1973) in Kentucky. They found greater nitrate accumulation in no-tilled soil than in plowed soils.

CS significantly increased soil NO<sub>3</sub> only in one trial at Kulumsa in the mechanised system, and the faba bean rotation increased soil NO<sub>3</sub> compared with CW. Grain legumes in the cropping sequence generally increases soil nitrate more than monocropping (Badaruddin & Meyer, 1994).

The effect of tillage on the NH<sub>4</sub> levels was inconsistent. Soil NH<sub>4</sub> was significantly affected by tillage in 1996 in the Kulumsa mechanised and Asasa ox-plow trials. The soil NH<sub>4</sub> was significantly higher in the CT treatment than MT at Kulumsa. In contrast, MT led to significantly higher the NH<sub>4</sub> levels in the soil at the Asasa ox-plow trial as compared to CT. No till can result in more organic C and N closer to surface than conventional tillage systems (Doran, 1980). Nitrogen immobilisation is enhanced and nitrification rates are lower under no-till when compared with conventional tillage (Stinner *et al.*, 1983).

**Soil phosphorus:**

Soil phosphorus in general decreased with depth because P is a less mobile plant nutrient in the soil profile. Minimum tillage had a significantly higher soil P than CT in one trial at Asasa in 1998. The accumulation of P near the soil surface and decreasing P levels deeper in the soil profile often result in higher soil test P levels at the surface compared to where

the soil is inverted by tillage (Cruse *et al.*, 1983; Triplett & van Doren, 1969). Several of these studies attributed the stratification of P to its slow movement into the soil profile and to fertiliser P being applied by surface broadcasting.

#### *Soil Potassium:*

SM significantly affected the soil K content in the Kulumsa mechanised trial during 1998 and 1999, where retention of stubble had a significantly higher soil K content. The retention of stubble residues on the soil surface reduces the rate of decomposition of stubble. In contrast burial of stubble result in rapid decomposition of the residues and partial incorporation of the stubble allows decomposition to proceed at an intermediate rate (Summerell & Burgess, 1989). The rate of stubble decomposition is favoured by the intimate soil-straw contact that follows tillage (Douglas *et al.*, 1980; Takana, 1986).

Soil K content was significantly affected by CS in the treatments of the Asasa mechanised trial during 1999 and Kulumsa ox-plow trial during 1998 with CW markedly increasing the soil K content. This might be due to higher straw concentrations in the wheat plots than in faba bean plots. Thus, the soil K content depends on the amount of wheat straw returned to the soil.

#### *Soil organic matter content:*

SM significantly affected soil organic matter at both sites in the mechanised system trials. In both cases retention of crop stubble on the soil surface ensured the highest organic matter content of the soil.

Tillage significantly affected soil organic matter only in the mechanised trial at Kulumsa. In this trial, ZT had a higher soil organic matter content compared with conventional tillage. Thus, the distribution of organic matter and nutrients in a soil profile may be changed when no-tillage practices are adopted. Organic C, N and P concentrations have been found to be greatly higher in the surface soil under no-tillage compared to conventional tillage (Blevins *et al.*, 1977; Dick, 1983). This surface accumulation of

organic and inorganic nutrients creates an environment where microbial growth and activity may be greatly stimulated.

CS significantly affected soil organic matter content in both the mechanised trials. At both locations, CW had a higher soil organic matter content than the faba bean rotation. This might be due to the higher biomass addition of wheat straw in the continuous wheat cropping system.

### *Weeds:*

SM had a relatively consistent effect on total broad leaf weeds (TBW), total grass weeds (TGW) and weed seedling density across the trials and seasons. Burning of crop stubble markedly reduced the weed seedling population compared with the other two treatments. Complete stubble retention tended to increase weed seedling densities to a greater extent. The stubble was usually burnt in late January, when little if any weed seeds would have germinated. Therefore, burning most likely destroyed the seeds itself rather than young seedlings. Burning of wheat and barley stubble has been shown to destroy seeds of black grass and wild oats (Wilson & Cussans, 1975).

*Bromus pectinatus* was the dominant grass weed species over the trial period. *Bromus* density was significantly reduced by stubble burning most of the years of this study. *Brome* grass is an extremely aggressive weed and yield losses as high as 50% have been reported (Poole & Gill, 1979) and it can also cause contamination of cereals seed thus lowering the quality. Because there are no affordable herbicides available for the control of brome in wheat, it is important to develop cultural practices which can control the production of new seeds. Several workers have indicated that brome seed has a short innate dormancy (Gill & Blacklow, 1985, Harradine, 1986).

TBW densities were lower under CT as compared to ZT or MT in both the mechanised and ox-plow systems. The response of individual weed species to tillage did not exhibit a common trend. Thus, *G. scarba* was reduced under ZT or MT in the Kulumsa mechanised and Asasa ox-plow trials. In contrast in the mechanised trial at Asasa and ox-plow trial at Kulumsa, MT markedly increased the *G. scarba* density cf. conventional tillage. In an

earlier study, it was found that *Amaranthus spp* exhibited poor germination on zero-till plots, and *Guizotia scabra*, *Galisoga parviflora* and *Galium spurium* occurred at lower densities under zero-tillage compared to conventional tillage (Giref & Tanner, 1992). In the current study the population of *A. hybridus* was significantly higher under CT as compared to ZT or MT in all the site and season combinations.

*Bromus pectinatus* seedling density was significantly affected by tillage in both the mechanised trials at both sites. ZT or MT markedly increased the seedling density of *Bromus* cf. conventional tillage. It was reported that Downy brome was especially a problem in conservation tillage because surface residues created an ideal niche for grass annual winter weed establishment (Thill *et al.*, 1984).

CS significantly affected TBW seedling density at both sites in the mechanised trials. The faba bean-wheat crop rotation had a significantly higher TBW density than the continuous wheat treatment. CS significantly affected TGW seedling density in all system trials across locations where continuous wheat had the highest TGW seedling density. Thus, crop rotation can improve the overall weed management systems especially by interrupting the life cycle and suppressing the growth development and dispersion of annual winter grass weeds (Strand, 1990). CS significantly affected the *Bromus* seeding density in the Asasa mechanised and in the ox-plow trial at both sites, where CW increased the population density of *Bromus*.

#### *Plant diseases:*

Stubble management practices had no effect on take-all incidences in any of the four trials, but full stubble retention increased the eyespot incidence. This is in contrast with the following results reported in literature. Burning stubble before sowing did not affect the incidence of take-all in continuously cropped direct drilled wheat in North Eastern Victoria (de Boer *et al.*, 1993), but reduced the level of the disease in wheat sown after lupins in New South Wales (Murray *et al.*, 1991). Kollmorgen *et al.* (1987) found that stubble mulches reduced the survival of take-all in buried straw in the Wimmera region of Victoria and suggested that mulching may reduce the carry-over of the fungus. Eyespot could survive between seasons on crop residues, particularly on old stubble (de Boer *et al.*,

1993). The removal of straw by burning could, therefore, be expected to reduce the incidence of eyespot. Eyespot was reported to be more prevalent where residues were either retained on the surface or incorporated in the soil by plow (Slope *et al.*, 1970). Yarham & Hirst (1975) reported results showing that direct drilling either increased or had no effect on the severity of eyespot compared with plow. Herman & Wiese (1985) found eyespot to be more common in ploughed plots, intermediate in minimum tilled plots, and the least common in no-till plots. The highest incidence of eyespot can be associated with stubble retention in continuously cropped, direct-drilled wheat (de Boer *et al.*, 1993). They also showed that conventional tillage combined with stubble burning resulted in eyespot levels similar to direct sowing in stubble, presumably because cultivation brought previously buried infected crop debris to the surface. Thus, wheat production with full stubble retention, particularly under conservation tillage practices, might in future have an adverse effect on the level of eyespot of wheat in Ethiopia.

Conservation tillage significantly reduced the incidence of take-all in the mechanised trials at both locations, but the reduction was more pronounced at Asasa (MT) than at Kulumsa (ZT). However, Scott (1969) reported that cultivation immediately after harvesting significantly reduced the number of white heads caused by take-all in the subsequent wheat crop, as compared with later cultivation. He concluded that this was probably due to enhanced microbial activity and greater competition for nitrogen in the well-aerated mixture of soil and stubble. Moore & Cook (1984) found that the best take-all control in consecutive crops of wheat was achieved through tillage.

#### *Economic aspects:*

A partial budget analysis revealed that the economic optimum treatments for each trial generally reflected the trade-off between the yield differential between faba bean and continuous wheat at each specific location and production system versus the yield advantage for wheat in rotation with faba bean relative to continuous wheat. Nevertheless, the index of variability (IV) of the nett benefit of each of the four trials did not markedly vary between the lowest-cost and the economic optimum treatments. Thus, stability of

farm level income would not be markedly affected by adoption of economic optimum cropping practices in each zone and production system.

*Pot Experiment:*

Several interesting results were obtained with a pot experiment under controlled conditions, where different straw management practices were compared. Straw burning resulted in the highest above-ground seedling biomass, while soil incorporation of the straw resulted in poorer growth. The retention of the straw on the surface gave inconsistent results. The reduction of wheat seedling growth in the incorporation treatment was probably due to allelopathic effects of wheat residue, because many crops residue including wheat straw, contains allelopathic compounds which retard the growth of seedlings (Guenzi & McCalla, 1966). The application rate of the straw was quite consistent for all the measured seedling parameters for both soils. Straw applications higher than 2.5 t/ha depressed all the seedling growth parameters. The rate of straw decomposition is primarily influenced by environmental and management factors (Tanaka, 1986) and large quantities of straw might take longer for decomposition to release the available nutrients for plant growth and development. Partly decomposed and fresh straw were compared in the pot experiment. Naturally degraded straw significantly increased most of the seedling growth parameters included in the analysis, for the Kulumsa soil. The concentration of soil organic carbon also depends on the rate of straw decomposition (Parr & Papendick, 1978). In the current pot trial straw application exhibited negative effects upon most of the seedling parameters than nil straw (i.e., the control) which exhibited higher values for the measured seedling parameters than the mean of 12 straw application treatments. Therefore, wheat straw should be properly decomposed in order to have well established wheat seedlings for both soils in Ethiopia.

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Appendix 3.1. Crop management effects on yield and yield components of wheat in the Kulumsa mechanised trial.

Yield and components	1993	1994	1995	1996	1997	1998	1999	2000
<i>Wheat variety</i>	Enkoy	Mitike	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa
<i>Grain yield (kg/ha)</i>	2203	1010	4969	5670	4309	3031	3815	2963
Straw management (SM)	NS	Bu>Rem, Ret=	NS	Ret>Bu, Rem=	Rem>Ret, Bu=	NS	NS	Bu >Rem=Ret
Tillage (T)	NS	CT>ZT	CT>ZT	NS	ZT>CT	NS	CT>ZT	CT>ZT
Cropping sequence (CS)	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW	---	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW	---	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW
Interaction (I)	NS	NS	NS	NS	NS	NS	TxC	SxT, SxC, TxC
<i>Biomass yield (kg/ha)</i>	7018	4306	10550	12600	10174	8847	9001	7400
SM	NS	Bu>Rem=Ret	NS	NS	NS	NS	NS	Bu >Rem=Ret
T	NS	CT>ZT	CT > ZT	NS	ZT>CT	NS	CT>ZT	CT>ZT
CS	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW	---	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW	---	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW
I	NS	NS	NS	NS	NS	NS	SxC, SxTxC	SxT, SxC, TxC
<i>Harvest index (%)</i>	31.6	26.2	46.6	43.6	43.3	34.1	42.5	40.8
SM	NS	NS	NS	NS	NS	Rem>Ret, Bu=	NS	NS
T	NS	NS	NS	NS	ZT>CT	NS	NS	ZT>CT
CS	CW>1 <sup>st</sup> W	NS	---	1 <sup>st</sup> W>CW	NS	---	NS	NS
I	NS	TxC	NS	TxC	NS	NS	NS	NS
<i>Spikes/m<sup>2</sup></i>	468	460	555	448	491	379	492	496
SM	NS	NS	NS	NS	Rem>Ret, Bu=	NS	NS	NS
T	NS	NS	ZT>CT	NS	NS	NS	NS	NS
CS	1 <sup>st</sup> W>CW	NS	---	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW	---	NS	NS
I	NS	NS	NS	NS	NS	NS	SxT	NS
<i>Grains/spike</i>	17.9	11.6	25.4	35.3	28.6	36.8	23.9	21.3
SM	NS	NS	NS	NS	NS	NS	NS	Bu >Rem=Ret
T	NS	NS	CT>ZT	NS	ZT>CT	NS	CT>ZT	CT>ZT
CS	1 <sup>st</sup> W>CW	NS	---	NS	NS	---	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW
I	NS	NS	NS	NS	NS	NS	SxTxC	NS

## Appendix 3.1. Continued.

Yield and components	1993	1994	1995	1996	1997	1998	1999	2000
<i>Thousand kernel wt. (g)</i>	23.8	19.4	34.9	35.1	32.5	22.5	33.4	30.1
SM	NS	NS	NS	Ret>Bu, Rem=	NS	Rem>Ret, Bu=	Rem>Ret, Bu=	NS
T	NS	NS	NS	NS	NS	NS	ZT>CT	ZT>CT
CS	NS	NS	---	1 <sup>st</sup> W>CW	NS	---	NS	CW>2 <sup>nd</sup> W
I	NS	NS	NS	TxC	NS	NS	NS	TxC
<i>Seedling biomass (kg/ha)</i>	---	---	262	1331	2063	1182	873	3707
SM	---	---	NS	NS	NS	NS	NS	Bu>Rem=Ret
T	---	---	NS	NS	NS	CT>ZT	NS	NS
CS	---	---	---	1 <sup>st</sup> W>CW	NS	---	NS	2 <sup>nd</sup> W>CW
I	---	---	NS	NS	S x C	NS	SxTxC	SxT



## Appendix 3.2. Continued.

Yield and components	1993	1994	1995	1996	1997	1998	1999	2000
<i>Thousand kernel wt. (g)</i>	19.2	20.6	30.8	32.7	29.5	29.6	34.1	31.1
SM	Ret>Bu, Rem=	NS	NS	NS	NS	NS	Ret>Rem>Bu	NS
T	NS	NS	MT>CT	MT>CT	NS	MT>CT	NS	MT>CT
CS	CW>1 <sup>st</sup> W	2 <sup>nd</sup> W>CW	---	1 <sup>st</sup> W>CW	NS	---	NS	NS
I	NS	TxC	NS	NS	NS	NS	NS	NS
<i>Seedling biomass (kg/ha)</i>	---	---	666	1249	1380	1396	1380	2815
SM	---	---	Bu>Rem, Ret=	Bu>Ret>Rem	NS	NS	NS	Bu=Ret>Rem
T	---	---	NS	NS	NS	NS	CT>MT	CT>MT
CS	---	---	---	NS	NS	---	1 <sup>st</sup> W>CW	NS
I	---	---	NS	NS	NS	NS	NS	NS

Appendix 3.3. Crop management effects on yield and yield components of wheat in the Kulumsa ox-plow trial.

Yield and components	1993	1994	1995	1996	1997	1998	1999	2000
<i>Wheat variety</i>	Enkoy	Mitike	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa
<i>Grain yield (kg/ha)</i>	2365	1217	4933	5713	4785	2969	3924	3742
Straw management (SM)	NS	NS	Bu>Rem	NS	NS	NS	NS	Bu>Rem
Tillage (T)	NS	CT>MT	CT>MT	NS	NS	NS	NS	CT>MT
Cropping sequence (CS)	NS	2 <sup>nd</sup> W>CW	---	1 <sup>st</sup> W>CW	NS	---	NS	2 <sup>nd</sup> W>CW
Interaction (I)	NS	NS	NS	SxC, TxC	SxT	NS	NS	SxC, TxC
<i>Biomass yield (kg/ha)</i>	7596	4615	10355	12395	11460	8056	8616	9118
SM	NS	NS	NS	NS	NS	Bu>Rem	NS	Bu>Rem
T	NS	CT>MT	CT>MT	NS	NS	NS	NS	CT>MT
CS	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW	---	1 <sup>st</sup> W>CW	NS	---	NS	2 <sup>nd</sup> W>CW
I	NS	NS	NS	SxC, TxC	NS	NS	NS	TxC
<i>Harvest index (%)</i>	31.0	26.5	47.3	44.6	42.8	37.1	45.2	41.6
SM	NS	NS	NS	NS	NS	NS	NS	Rem>Bu
T	NS	NS	NS	NS	NS	NS	NS	NS
CS	NS	NS	---	NS	NS	---	NS	NS
I	NS	NS	NS	NS	NS	NS	NS	NS
<i>Spikes/m<sup>2</sup></i>	441	339	297	358	375	366	331	392
SM	NS	NS	NS	Rem>Bu	NS	NS	Bu>Rem	Bu>Rem
T	NS	NS	NS	NS	NS	CT>MT	MT>CT	NS
CS	NS	2 <sup>nd</sup> W>CW	---	NS	NS	---	NS	NS
I	TxC	NS	NS	TxC	NS	NS	NS	SxTxC
<i>Grains/spike</i>	22.5	16.6	35.8	43.5	40.0	41.6	34.6	30.3
SM	NS	NS	NS	NS	NS	NS	NS	Bu>Rem
T	NS	NS	NS	NS	NS	NS	NS	NS
CS	NS	NS	---	NS	NS	---	NS	2 <sup>nd</sup> W>CW
I	NS	NS	NS	TxC	NS	NS	NS	TxC, SxTxC

## Appendix 3.3. Continued.

Yield and components	1993	1994	1995	1996	1997	1998	1999	2000
<i>Thousand kernel wt. (g)</i>	23.6	21.9	36.7	35.7	33.5	21.7	36.4	32.2
SM	NS	Bu>Ret	NS	Rem>Bu	NS	Rem>Bu	NS	NS
T	NS	NS	NS	MT>CT	MT > CT	MT>CT	NS	NS
CS	CW>1 <sup>st</sup> W	NS	---	1 <sup>st</sup> W>CW	NS	---	NS	NS
I	NS	NS	SxT	SxT	SxT	NS	TxC, SxTxC	SxT, TxC
<i>Seedling biomass (kg/ha)</i>	---	---	284	1446	1833	1928	926	1274
SM	---	---	NS	Bu>Rem	Bu>Rem	NS	NS	NS
T	---	---	NS	MT>CT	CT>MT	NS	NS	NS
CS	---	---	---	NS	NS	---	NS	2 <sup>nd</sup> W>CW
I	---	---	NS	NS	TxC	NS	SxC	NS



## Appendix 3.4. Continued

Yield and components	1993	1994	1995	1996	1997	1998	1999	2000
<i>Thousand kernel wt. (g)</i>	18.7	22.4	36.3	33.6	27.9	28.1	32.4	31.3
SM	NS	NS	NS	NS	NS	NS	NS	NS
T	NS	NS	NS	NS	MT>CT	NS	NS	NS
CS	NS	NS	---	1 <sup>st</sup> W>CW	NS	---	NS	CW>2 <sup>nd</sup> W
I	NS	NS	NS	NS	NS	NS	SxC	SxTxC
<i>Seedling biomass (kg/ha)</i>	---	---	301	1553	1671	2083	1356	932
SM	---	---	NS	Bu>Rem	NS	NS	NS	Bu>Rem
T	---	---	NS	CT>MT	NS	NS	CT>MT	NS
CS	---	---	---	1 <sup>st</sup> W>CW	NS	---	1 <sup>st</sup> W>CW	NS
I	---	---	NS	NS	NS	NS	NS	NS

Appendix 4.1. Effect of crop management practices on wheat N uptake in the mechanised system trial at Kulumsa from 1996-99: ANOVA results.

	1996					1997					1998					1999				
	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU
SM (S)	NS	NS	NS	NS	NS	NS	†	NS	†	NS	*	NS	NS	NS	NS	*	NS	†	NS	NS
Tillage (T)	†	†	NS	NS	NS	NS	NS	*	*	*	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
SxT	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	†	NS	NS	NS	NS	NS	*	NS
CS (C)	***	**	***	**	***	NS	NS	NS	**	*	--	--	---	---	---	NS	NS	*	†	*
SxC	†	NS	†	NS	NS	*	NS	*	*	NS	--	--	---	---	---	NS	NS	NS	*	†
TxC	*	NS	NS	NS	NS	NS	NS	NS	***	NS	--	--	---	---	---	NS	NS	NS	*	†
SxTxC	NS	NS	NS	NS	*	NS	NS	NS	*	NS	--	--	---	---	---	NS	NS	†	*	*
Mean	1.79	0.48	87.8	29.6	117	1.69	0.39	63.9	21.5	85.4	1.68	0.62	44.2	33.5	77.7	1.35	0.4	45.7	19.2	64.7
C.V.(%)	4.04	17.1	10.1	25.8	7.71	7.75	11.7	12.9	9.9	10.3	7.36	13.9	7.3	30.5	16.2	29.9	35	27.0	31.4	22.5

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SM = Straw management; CS = Cropping sequence.

Appendix 4.2. Effect of crop management practices on wheat N uptake in the mechanised system trial at Kulumsa from 1996-99: treatment means

	1996					1997					1998					1999				
	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU
SM (S)																				
Burn	1.79	0.46	82.9	28.9	112	1.68	0.42A	63.1	23.9A	87	1.68AB	0.63	46.9	37.1	84.0	1.57A	0.40	52.9A	17.6	70.6
Remove	1.71	0.49	89.1	30.0	119	1.67	0.38B	66.2	20.2B	86	1.61B	0.60	43.8	28.1	70.6	1.35AB	0.36	48.1A	17.2	65.3
Retention	1.77	0.49	91.5	29.8	121	1.74	0.38B	62.3	20.4AB	83	1.74A	0.64	42.9	35.3	78.5	1.12B	0.46	35.9B	22.7	58.7
LSD(5%)							0.04		3.64		0.07					0.28		10.9		
Tillage																				
Conven.	1.82A	0.51A	89.5	31.6	121	1.72	0.39	59.8B	19.2B	79A	1.69	0.62	46.6A	31.2	77.7	1.38	0.38	49.4	18.3	67.7
Zero	1.77B	0.45B	86.2	27.5	114	1.68	0.39	67.9A	23.9A	92B	1.66	0.63	42.0B	35.7	27.7	1.31	0.44	42.0	20.1	62.0
CS (C)																				
Faba bean	1.87A	0.53A	98.5A	34.4A	133A	1.67	0.40	65.8	22.9A	89A	--	--	---	---	---	1.42	0.42	50.2A	20.9	71.3A
Wheat	1.72B	0.42B	77.2B	24.8B	102B	1.77	0.39	61.9	20.1B	82B	--	--	---	---	---	1.27	0.40	40.9B	17.4	58.4B

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SM = Straw management; CS = Cropping sequence.

Appendix 4.3. Effect of crop management practices on wheat N uptake in the mechanised system trial at Asasa from 1996-99: ANOVA results.

	1996					1997					1998					1999				
	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU
SM (S)	NS	NS	*	NS	†	NS	NS	NS	*	NS	NS	NS	NS	†	NS	NS	NS	NS	NS	NS
Tillage (T)	*	NS	*	†	*	NS	**	NS	*	*	NS	*	NS	†	NS	*	NS	***	NS	**
SxT	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	NS	NS
CS (C)	*	NS	***	*	***	NS	NS	NS	NS	NS	---	---	---	---	---	*	NS	***	*	***
SxC	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	---	---	---	---	---	NS	NS	NS	NS	NS
TxC	†	NS	**	NS	*	NS	NS	NS	NS	NS	---	---	---	---	---	NS	NS	NS	†	NS
SxTxC	NS	NS	NS	NS	NS	†	NS	†	NS	†	---	---	---	---	---	NS	NS	NS	NS	NS
Mean	1.75	0.38	59.9	18.4	78.4	1.93	0.42	53.9	33.3	87.1	1.95	0.52	45.2	20.8	66.1	1.18	0.30	42.6	14.6	57.2
C.V.(%)	4.97	21.7	9.20	35.6	13.1	4.20	16.2	11.9	19.2	13.1	38.5	31.4	50.2	38.1	36.1	14.5	37.1	19.5	47.9	23.8

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SM = Straw management; CS = Cropping sequence.

Appendix 4.4. Effect of crop management practices on wheat N uptake in the mechanised system trial at Asasa from 1996-99: treatment means.

	1996					1997					1998					1999				
	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU
SM (S)																				
Burn	1.74	0.37	65A	20.2	85	1.99	0.44	57.3	34.5A	91.8	1.84	0.51	44.7	21.1	65.8	1.20	0.34	45.4	18.1	36.6
Remove	1.79	0.38	62A	17.8	80	1.92	0.39	52.7	30.4B	83.1	1.78	0.42	37.5	14.9	52.5	1.16	0.28	40.1	13.0	53.1
Retention	1.71	0.37	53B	17.1	70	1.88	0.44	51.7	34.9A	86.6	2.24	0.63	53.5	26.3	79.8	1.19	0.27	42.3	12.8	55.0
LSD(5%)			7.88						3.23											
Tillage																				
Conven.	1.78A	0.38	63A	19.5A	83A	1.97	0.46A	55.8	36.7A	92.5A	1.82	0.62A	41.6	24.9A	66.4	1.22A	0.29	46.7A	15.1	61.8A
Minimum	1.71B	0.37	57B	17.3B	74B	1.90	0.38B	52.0	29.9B	81.9B	2.08	0.42B	48.9	16.7B	65.7	1.14B	0.30	38.5B	14.2	52.7B
CS (C)																				
Faba bean	1.71B	0.37	68A	20.8A	89A	1.93	0.43	53.5	34.1	87.6	--	--	---	---	---	1.27A	0.31	53.9A	17.9A	71.8A
Wheat	1.78A	0.38	52B	15.9B	70B	1.93	0.42	54.3	32.5	86.8	--	--	---	---	---	1.09B	0.28	31.3B	11.4B	42.7B

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SM = Straw management; CS = Cropping sequence.

Appendix 4.5. Effect of crop management practices on wheat N uptake in the ox-plow system trial at Kulumsa from 1996-99: ANOVA results

	1996					1997					1998					1999				
	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU
SM (S)	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T)	*	***	NS	**	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS
SxT	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CS (C)	***	***	***	**	***	NS	NS	NS	NS	NS	--	--	--	--	---	*	NS	*	NS	***
SxC	NS	*	**	NS	**	NS	NS	†	NS	NS	--	--	--	--	---	NS	NS	NS	NS	NS
TxC	NS	NS	*	NS	*	NS	NS	NS	NS	NS	--	--	--	--	---	NS	*	NS	†	NS
SxTxC	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--	--	--	---	NS	NS	NS	NS	NS
Mean	1.83	0.44	91.5	27.2	119	1.59	0.47	66.6	29.1	95.7	1.71	0.60	44.1	28.3	72.6	1.47	0.37	52.2	16.0	68.1
C.V.(%)	3.03	9.21	4.89	14.1	5.77	4.19	25.03	6.82	34.6	9.55	4.97	7.60	18.3	35.3	24.3	19.9	41.5	28.5	49.9	23.7

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SM = Straw management; CS = Cropping sequence.

Appendix 4.6. Effect of crop management practices on wheat N uptake in the ox-plow system trial at Kulumsa from 1996-99: treatment means.

	1996					1997					1998					1999				
	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU
SM (S)																				
Burn	1.87A	0.46	91.1	27.7	119	1.62	0.50	68.3	31.1	99.4	1.72	0.60	46.4	30.6	77.0	1.44	0.38	51.3	17.3	68.6
Remove	1.79B	0.43	92.0	26.8	119	1.56	0.43	64.9	27.1	92.0	1.69	0.59	42.2	25.9	68.1	1.50	0.36	53.0	14.6	67.6
Tillage																				
Conven.	1.86A	0.50A	92.1	31.5A	124	1.59	0.50A	66.9	31.7	98.6	1.68	0.54	45.5	24.2	69.6	1.52	0.35	51.5	15.2	66.7
Minimum	1.80B	0.39B	90.9	22.9B	114	1.59	0.43B	66.3	26.5	92.9	1.73	0.65	43.1	32.3	75.5	1.42	0.39	52.9	16.7	69.7
CS (C)																				
Faba bean	1.90A	0.49A	99.5A	30.6A	130A	1.61	0.50	68.1	29.2	97.2	--	--	---	---	---	1.61A	0.41	61.5A	18.4	79.8A
Wheat	1.76B	0.39B	83.6B	23.8B	107B	1.58	0.44	65.1	29.1	94.3	--	--	---	---	---	1.33B	0.32	42.9B	13.6	56.4B

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SM = Straw management; CS = Cropping sequence.

Appendix 4.7. Effect of crop management practices on wheat N uptake in the ox-plow system trial at Asasa from 1996-99: ANOVA results

	1996					1997					1998					1999				
	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU
SM (S)	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	*	NS	*
Tillage (T)	NS	NS	NS	NS	NS	NS	NS	*	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SxT	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS
CS (C)	NS	*	***	*	***	NS	NS	NS	NS	NS	--	--	--	--	--	†	NS	**	*	**
SxC	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--	--	--	--	NS	*	NS	NS	NS
TxC	*	NS	†	NS	NS	NS	NS	NS	NS	NS	--	--	--	--	--	NS	NS	NS	NS	NS
SxTxC	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	--	--	--	--	NS	NS	NS	NS	NS
Mean	1.62	0.33	54.1	15.9	70.0	1.75	0.39	47.9	19.5	67.4	1.57	0.51	43.3	24.4	67.7	1.42	0.52	48.7	25.8	74.5
C.V.(%)	1.83	8.48	9.55	30.3	13.4	6.27	13.3	12.2	17.1	11.5	7.18	17.7	21.9	20.9	9.9	21.3	27.5	19.9	38.4	25.2

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SM = Straw management; CS = Cropping sequence.

Appendix 4.8. Effect of crop management practices on wheat N uptake in the ox-plow system trial at Asasa from 1996-99: treatment means

	1996					1997					1998					1999				
	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU	GN%	SN%	GNU	SNU	TNU
SM (S)																				
Burn	1.61	0.32	57.4A	17.4	74.9	1.75	0.40	48.1	20.1	68.2	1.59	0.53	47.3	28.5	75.8	1.46A	0.54	55.1A	30.6	85.8A
Remove	1.63	0.33	50.8B	14.4	65.2	1.75	0.39	47.6	18.9	66.6	1.59	0.50	39.3	20.1	59.5	1.38B	0.49	42.3B	20.9	63.2B
Tillage																				
Conven.	1.61	0.33	55.7	16.5	72.2	1.75	0.39	45.4B	18.6	64.1B	1.55	0.51	43.5	27.1	70.6	1.41	0.50	48.7	25.7	74.4
Minimum	1.63	0.33	52.5	15.4	67.9	1.75	0.39	50.3A	20.5	70.8A	1.60	0.52	43.1	21.6	64.7	1.43	0.53	48.8	25.8	74.5
CS (C)																				
Faba bean	1.62	0.35A	60.8A	19.1A	79.9A	1.71	0.39	48.7	20.3	68.9	--	--	---	---	---	1.54	0.55	61.1A	32.1A	93.2A
Wheat	1.61	0.31B	47.4B	12.7B	60.1B	1.79	0.39	47.1	18.8	65.9	--	--	---	---	---	1.30	0.48	36.3B	19.4B	55.7B

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha);

SM = Straw management; CS = Cropping sequence.

Appendix 4.9. Effects of interaction of straw management by cropping sequence on N uptake in the mechanised and ox-plow system trials at Kulumsa and Asasa.

CS	Kulumsa mechanised									Kulumsa ox-plow				Asasa ox-plow				
	GNU1996			SNU1997			SNU1999			TNU1999			GNU1996		TNU1996		SN%1999	
	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Burn	Remove	Burn	Remove
FB	91BC	97A	107A	27A	20BCD	22B	18B	17B	29A	70A	72A	72A	103A	96B	135A	125B	0.65A	0.45B
CW	75D	81CD	76D	21BC	20CD	19D	18B	18B	17B	72A	58AB	45B	79D	88C	102D	113C	0.43B	0.53AB
LSD(5%)	11.2			1.55			7.57			18.4			5.96		9.12		0.19	

Values followed by the same letter within each parameter are not significantly different at the 5% level of the LSD test.

GNU = Grain N uptake; SNU = Straw N uptake; TNU = Total N uptake; CS = Cropping sequence; FB = Faba bean rotation; CW = Continuous wheat.

Appendix 4.10. Effects of interaction of tillage by cropping sequence on N uptake in the mechanised and ox-plow system trials at Kulumsa and Asasa.

CS	Kulumsa mechanised						Asasa mechanised						Kulumsa ox-plow						Asasa ox-plow			
	SNU1997		SNU1999		TNU1999		GNU1996		TNU1996		SNU1999		GNU1996		TNU1996		SN%1999		SNU1999		GNU1996	
	Con	Zero	Con	Zero	Con	Zero	Con	Min	Con	Min	Con	Min	Con	Min	Con	Min	Con	Min	Con	Min	Con	Min
FB	19C	27A	18AB	19AB	69A	74A	68A	68A	89A	89A	16AB	14AB	103A	97B	138A	122B	0.33AB	0.50A	14AB	23A	60A	61A
CW	19C	21B	24A	16B	66A	50B	58B	46C	77B	59C	20A	9B	82C	86C	109C	106C	0.37AB	0.27B	16AB	11B	51B	44C
LSD(5%)	1.26		6.18		15.0		5.66		10.5		7.20		5.96		9.12		0.20		10.6		6.88	

Values followed by the same letter within each parameter are not significantly different at the 5% level of the LSD test.

GNU = Grain N uptake; SNU = Straw N uptake; TNU = Total N uptake; CS = Cropping sequence; FB = Faba bean rotation; CW = Continuous wheat; Con = Conventional tillage; Min = Minimum tillage.

Appendix 4.11. Effects of interaction of straw management by tillage on N uptake in the mechanised and ox-plow system trials at Kulumsa and Asasa.

Tillage	Kulumsa mechanised						Asasa mechanised			Asasa ox-plow			
	GNU1998			SNU1999			SNU1998			SNU1998		TNU1998	
	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Burn	Remove
Conventional	49A	42BC	48A	18B	18B	19B	20B	16B	38A	36A	19A	85A	57B
Minimum	45AB	43B	38C	17B	16B	27A	22B	14B	14B	21B	22B	67B	63B
LSD(5%)	4.50			4.53			15.8			8.15		10.7	

Values followed by the same letter within each parameter are not significantly different at the 5% level of the LSD test.

GNU = Grain N uptake; SNU = Straw N uptake; TNU = Total N uptake.

Appendix 5.1. Effect of crop management practices on pre-planting soil chemical properties in the mechanised system trial at Kulumsa: ANOVA results for 1996-99.

Treatment	pH 96	pH 97	pH 98	pH 99	NO <sub>3</sub> 96	NO <sub>3</sub> 97	NO <sub>3</sub> 98	NH <sub>4</sub> 96	NH <sub>4</sub> 97	NH <sub>4</sub> 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)	NS	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	†	NS	**
Tillage (T)	NS	†	NS	NS	†	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CS (C)	NS	NS	NS	NS	*	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS
S x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS
T x C	NS	N	NS	NS	NS	†	NS	NS	NS	NS	NS	†	*	NS	NS	NS	NS	NS
S x T x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Depth (cm)	*	**	***	***	**	NS	***	**	NS	***	***	NS	***	***	***	***	***	***
S x D	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	†	†	*	†	NS
T x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	*	NS	NS
S x T x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	†	NS	†
C x D	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
S x C x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	NS	NS	NS
T x C x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x T x C x D	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	†	NS	NS	NS	NS	NS	NS	NS
Mean	6.2	5.50	6.22	6.08	18.7	28.4	12.9	17.4	10.4	11.4	24.1	15.5	7.27	3.47	732.1	351	0.24	0.61
C.V.(%)	2.3	4.34	2.62	5.73	13.4	19.3	41.3	17.2	15.9	22.4	9.39	22.9	75.4	78.0	8.17	8.38	26.5	19.7

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H<sub>2</sub>O); NO<sub>3</sub>; NH<sub>4</sub>; P, K and Zn (mg kg<sup>-1</sup>).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.2. Effect of crop management practices on pre-planting soil chemical properties in the mechanised system trial at Kulumsa: treatment means for 1996-99.

Treatment	pH 96	pH 97	pH 98	pH 99	NO <sub>3</sub> 96	NO <sub>3</sub> 97	NO <sub>3</sub> 98	NH <sub>4</sub> 96	NH <sub>4</sub> 97	NH <sub>4</sub> 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)																		
Burn	6.13	5.68	6.29	6.22A	18.1	28.9	15.9	16.3	10.1	10.1	27.7	15.9	6.28	3.99	720B	352AB	0.24	0.56B
Removal	6.28	5.45	6.04	6.03AB	18.6	31.8	11.9	17.9	11.0	12.5	24.6	19.8	8.74	3.12	704C	327B	0.25	0.57B
Retention	6.10	5.37	6.32	5.98B	19.5	24.4	10.9	18.1	10.0	11.6	25.0	13.7	6.77	3.31	772A	373A	0.24	0.70A
LSD(5%)				0.21											2.7	41.1		0.12
Tillage																		
Conventional	6.15	5.52	6.20	6.06	17.6	27.8	13.8	17.6A	10.6	11.6	23.9	16.0	6.33	3.28	719	358	0.25	0.62
Zero	6.19	5.48	6.24	6.09	19.8	29.0	12.2	17.2B	10.2	11.2	24.2	16.7	8.19	3.78	746	343	0.24	0.60
CS (C)																		
Faba bean	6.14	5.48	6.22	6.03	19.5A	28.7	14.5	17.3	10.4	11.7	24.2	16.9	6.93	3.23	720	345	0.25	0.62
Wheat	6.19	5.52	6.22	6.12	17.9B	28.2	11.5	17.6	10.4	11.1	23.9	15.9	7.60	3.71	744	356	0.24	0.60
Depth (cm)																		
0-15	6.12B	5.44B	5.84C	5.82C	17.6B	29.5	21.7A	16.2B	10.8	12.4A	25.6A	16.5	13.3A	6.81A	813A	400A	0.34A	0.91A
15-30	6.16AB	5.45B	6.21B	6.07B	18.8A	28.9	11.2B	18.4A	10.2	11.9A	23.2B	16.4	6.4B	2.56B	699B	338B	0.22B	0.63B
30-60	6.23A	5.61A	6.60A	6.34A	19.7A	26.9	6.1C	17.8A	10.2	9.9B	23.5B	16.3	2.0C	1.04C	684B	314C	0.16C	0.29C
LSD(5%)	0.07	0.11	0.08	0.17	1.18		2.53	1.43		1.21	1.07		2.30	0.28	28.3	13.9	0.03	0.10

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H<sub>2</sub>O); NO<sub>3</sub>; NH<sub>4</sub>; P, K and Zn (mg kg<sup>-1</sup>).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.3. Effect of crop management practices on pre-planting soil chemical properties in the mechanised system trial at Asasa: ANOVA results for 1996-99.

Treatment	pH 96	pH 97	pH 98	pH 99	NO <sub>3</sub> 96	NO <sub>3</sub> 97	NO <sub>3</sub> 98	NH <sub>4</sub> 96	NH <sub>4</sub> 97	NH <sub>4</sub> 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T)	NS	NS	†	*	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CS (C)	NS	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	†	NS	*	NS	*	NS	NS
S x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	NS
T x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x T x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	†	NS	NS	NS
Depth (cm)	***	**	***	**	***	***	***	**	NS	NS	**	***	***	***	***	***	***	***
S x D	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	*
T x D	†	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS	**	NS	†	NS	NS
S x T x D	NS	†	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
S x C x D	†	†	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	NS	NS	NS
T x C x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
S x T x C x D	NS	†	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	†	NS	NS	NS	NS
Mean	5.79	5.62	5.96	6.11	21.6	25.5	20.2	9.64	20.2	13.0	28.2	30.4	11.2	9.67	742.4	410	0.90	0.84
C.V.(%)	3.41	2.04	4.15	6.70	20.4	33.5	42.0	15.2	13.9	43.8	16.9	12.0	35.4	32.4	15.4	23.7	28.9	23.1

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H<sub>2</sub>O); NO<sub>3</sub>; NH<sub>4</sub>; P, K and Zn (mg kg<sup>-1</sup>).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.4. Effect of crop management practices on pre-planting soil chemical properties in the mechanised system trial at Asasa: treatment means for 1996-99

Treatment	pH 96	pH 97	pH 98	pH 99	NO <sub>3</sub> 96	NO <sub>3</sub> 97	NO <sub>3</sub> 98	NH <sub>4</sub> 96	NH <sub>4</sub> 97	NH <sub>4</sub> 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)																		
Burn	5.78	5.54	5.82B	6.04	20.5	24.0	22.1	9.59	10.8	13.5	28.6	28.9	11.8	10.5	737	427	0.92	0.86
Removal	5.70	5.77	5.87AB	6.01	20.5	24.6	21.2	9.45	11.4	14.0	39.9	31.3	12.3	9.48	738	381	0.99	0.94
Retention	5.89	5.56	6.18A	6.28	23.9	27.8	17.5	9.78	10.5	11.3	36.1	31.1	9.5	9.05	753	422	0.79	0.71
LSD(5%)			0.36															
Tillage																		
Conventional	5.82	5.67	5.88	6.06B	22.3	25.1	23.9A	9.67	10.8	13.2	38.2	30.6	11.9	10.2	746	410	0.93	0.86
Minimum	5.76	5.65	6.03	6.16A	20.9	25.8	16.6B	9.60	11.0	12.7	38.2	30.3	10.5	9.18	739	410	0.87	0.79
CS (C)																		
Faba bean	5.77	5.64	5.91	6.01	21.9	24.7	20.8	9.50	10.8	13.2	38.6	29.7	10.8	8.80B	733	392B	0.93	0.80
Wheat	5.81	5.61	5.99	6.21	21.3	26.2	19.7	9.78	11.0	12.8	37.9	31.1	11.6	10.5A	752	428A	0.86	0.87
Depth (cm)																		
0-15	5.64C	5.50C	5.58C	5.76C	23.4A	28.9A	32.8A	10.2A	11.2	13.9	41.5A	36.9A	21.6A	17.8A	853A	495A	1.28A	1.26A
15-30	5.77B	5.60B	5.80B	6.08B	23.1A	27.0A	19.9B	9.46B	10.9	13.6	36.3B	28.3B	9.4B	8.01B	643C	358B	1.01B	0.94B
30-60	5.96A	5.78A	6.48A	6.49A	18.5B	20.5B	8.0C	9.28B	10.6	11.4	36.9B	26.0C	2.6C	3.13C	731B	377B	0.40C	0.31C
LSD(5%)	0.94	0.05	0.08	0.24	2.09	4.05	4.03	0.70			3.08	1.74	1.85	1.48	54.2	46.1	0.12	0.09

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H<sub>2</sub>O); NO<sub>3</sub>, NH<sub>4</sub>; P, K and Zn (mg kg<sup>-1</sup>).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.5. Effect of crop management practices on pre-planting soil chemical properties in the ox-plow system trial at Kulumsa: ANOVA results for 1996-99

Treatment	pH 96	pH 97	pH 98	pH 99	NO <sub>3</sub> 96	NO <sub>3</sub> 97	NO <sub>3</sub> 98	NH <sub>4</sub> 96	NH <sub>4</sub> 97	NH <sub>4</sub> 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T)	NS	†	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	†	NS	NS	NS	NS	NS
S x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CS (C)	**	NS	NS	*	†	NS	NS	*	NS	NS	NS	NS	NS	†	*	NS	NS	NS
S x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T x C	**	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x T x C	NS	NS	NS	†	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	*
Depth (cm)	*	**	***	NS	†	NS	***	**	NS	***	***	*	***	**	***	***	***	***
S x D	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS
T x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	**	NS	*	†
S x T x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS
S x C x D	NS	NS	NS	NS	NS	NS	*	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS
T x C x D	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS
S x T x C x D	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS
Mean	6.17	5.57	6.3	5.90	19.6	33.3	12.9	10.2	11.9	13.8	23.6	12.7	5.95	4.53	668.1	364	0.46	0.81
C.V.(%)	2.20	3.84	6.1	7.39	11.8	15.9	44.8	15.1	11.7	21.7	7.04	35.2	37.5	32.7	9.72	15.9	27.5	17.9

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H<sub>2</sub>O); NO<sub>3</sub>; NH<sub>4</sub>; P, K and Zn (mg kg<sup>-1</sup>).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.6. Effect of crop management practices on pre-planting soil chemical properties in the ox-plow system trial at Kulumsa: treatment means for 1996-99.

Treatment	pH 96	pH 97	pH 98	pH 99	NO <sub>3</sub> 96	NO <sub>3</sub> 97	NO <sub>3</sub> 98	NH <sub>4</sub> 96	NH <sub>4</sub> 97	NH <sub>4</sub> 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)																		
Burn	6.11B	5.51	6.23	5.92	19.9	33.1	14.5	9.99	11.7	14.4	23.5	14.2	5.84	4.75	657	377	0.43	0.84
Removal	6.23A	5.42	6.40	5.89	19.2	33.6	11.3	10.3	12.1	13.2	23.7	11.2	6.06	4.31	679	352	0.49	0.78
Tillage																		
Conventional	6.19	5.41	6.34	5.89	17.9	33.4	12.6	10.0	11.7	14.9	23.8	13.9	5.40	4.48	664	370	0.46	0.81
Minimum	6.15	5.53	6.28	5.92	21.2	33.2	13.3	10.3	12.2	12.6	23.5	11.5	6.50	4.58	673	359	0.46	0.81
CS (C)																		
Faba bean	6.15B	5.47	6.32	5.84B	20.4	32.9	14.1	9.8B	11.9	14.4	23.8	12.2	5.65	4.23	651B	357	0.43	0.80
Wheat	6.20A	5.46	6.31	5.97A	18.7	33.7	11.8	10.5A	11.8	13.2	23.4	13.2	6.25	4.84	685A	372	0.48	0.81
Depth (cm)																		
0-15	6.13B	5.37B	5.81C	5.82	18.7B	35.2	23.4A	9.3B	11.9	15.8A	24.6A	14.6A	11.8A	9.11A	740A	411A	0.61A	1.20A
15-30	6.14B	5.46AB	6.27B	5.91	20.1A	32.2	9.6B	10.9A	11.9	14.2A	23.9A	12.3AB	4.1B	3.13B	645B	335B	0.45B	0.85B
30-60	6.24A	5.58A	6.86A	5.98	19.8AB	32.5	5.8C	10.2AB	12.0	11.4B	22.4B	11.2B	1.9C	1.35C	619B	317B	0.30C	0.38C
LSD(5%)	0.08	0.12	0.23		1.35		3.41	0.99		1.76	0.97	2.62	1.31	0.87	38.2	34.0	0.07	0.09

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H<sub>2</sub>O); NO<sub>3</sub>; NH<sub>4</sub>; P, K and Zn (mg kg<sup>-1</sup>).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.7. Effect of crop management practices on pre-planting soil chemical properties in the ox-plow system trial at Asasa: ANOVA results for 1996-99

Treatment	pH 96	pH 97	pH 98	pH 99	NO <sub>3</sub> 96	NO <sub>3</sub> 97	NO <sub>3</sub> 98	NH <sub>4</sub> 96	NH <sub>4</sub> 97	NH <sub>4</sub> 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	NS	NS
Tillage (T)	NS	†	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS	NS	NS	NS	†
S x T	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS	†	NS	NS	NS	NS	NS
CS (C)	NS	NS	NS	†	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	NS
T x C	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
S x T x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	*
Depth (cm)	***	***	***	*	**	***	***	NS	NS	***	***	***	***	*	***	*	***	***
S x D	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS
T x D	*	NS	†	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
S x T x D	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x D	NS	†	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x C x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T x C x D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x T x C x D	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Mean	6.09	5.67	6.01	6.07	21.7	24.9	19.8	9.3	9.7	11.4	31.8	28.4	10.5	7.86	722	382	0.58	0.87
C.V.(%)	3.75	3.64	3.75	7.63	15.1	15.1	31.3	25.4	20.7	29.8	14.4	11.5	37.5	39.9	11.6	21.0	26.1	31.3

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H<sub>2</sub>O); NO<sub>3</sub>; NH<sub>4</sub>; P, K and Zn (mg kg<sup>-1</sup>).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.8. Effect of crop management practices on pre-planting soil chemical properties in the ox-plow system trial at Asasa: treatment means for 1996-99.

Treatment	pH 96	pH 97	pH 98	pH 99	NO <sub>3</sub> 96	NO <sub>3</sub> 97	NO <sub>3</sub> 98	NH <sub>4</sub> 96	NH <sub>4</sub> 97	NH <sub>4</sub> 98	P 96	P 97	P 98	P 99	K 98	K 99	Zn 98	Zn 99
SM (S)																		
Burn	6.11	5.72	6.04	6.04	22.8	23.9	21.4	9.88	9.2	10.8	32.6	29.5	11.2	8.12	598	390	0.58	0.89
Removal	6.07	6.61	5.98	6.10	20.5	25.9	18.2	8.73	10.2	11.9	31.0	27.3	9.8	7.60	551	375	0.58	0.52
Tillage																		
Conventional	6.14	5.73	6.07	6.11	21.9	25.4	19.2	9.10B	9.3	11.7	31.3	27.9	8.7B	7.99	558	379	0.58	0.89
Minimum	6.05	5.60	5.96	6.03	21.4	24.5	20.4	9.51A	10.1	11.1	32.3	28.8	12.3A	7.73	591	385	0.57	0.85
CS (C)																		
Faba bean	6.04	5.71	5.98	5.98	22.1	23.9	19.3	9.56	9.6	11.9	32.5	28.4	10.1	8.12	574	372	0.59	0.88
Wheat	6.15	5.62	6.04	6.16	21.1	25.9	20.4	9.05	9.7	10.8	31.2	28.3	10.8	7.60	564	393	0.59	0.86
Depth (cm)																		
0-15	5.97B	5.46C	5.54C	5.84B	23.4A	30.2A	31.8A	9.38	9.9	12.6A	35.2A	31.9A	20.1A	15.7A	627A	373AB	0.91A	1.47A
15-30	6.02B	5.62B	5.85B	6.13A	21.9A	23.6B	20.1B	9.25	9.7	12.4A	31.7B	26.8B	8.4B	5.41B	483B	353B	0.60B	0.82B
30-60	6.29A	5.93A	6.65A	6.24A	19.7B	21.2B	7.6C	9.29	9.5	8.9B	28.6C	26.6B	3.0C	2.45C	614A	421A	0.22C	0.32C
LSD(5%)	0.13	0.12	0.13	0.27	1.92	2.22	3.65			1.99	2.67	1.91	2.28	1.85	39.3	49.0	0.09	0.16

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SM = Straw management; CS = Cropping sequence.

pH (1:1 H<sub>2</sub>O); NO<sub>3</sub>; NH<sub>4</sub>; P, K and Zn (mg kg<sup>-1</sup>).

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.9. Effects of interaction of straw management by depth on pre-planting soil chemical properties in the mechanised trial at Kulumsa.

Depth	NH <sub>4</sub> (mg kg <sup>-1</sup> ) 1996			K (mg kg <sup>-1</sup> ) 1998			Zn (mg kg <sup>-1</sup> ) 1998			P (mg kg <sup>-1</sup> ) 1999			K (mg kg <sup>-1</sup> ) 1999			Zn (mg kg <sup>-1</sup> ) 1999		
	Burn	Removal	Retain	Burn	Removal	Retain	Burn	Removal	Retain	Burn	Remove	Retain	Burn	Remove	Retain	Burn	Remove	Retain
0-15	16.5CDE	15.6DE	16.4CDE	798B	768BC	873A	0.32A	0.36A	0.33A	8.79A	5.43B	6.22B	397B	363C	441A	0.86B	0.88B	0.99A
15-30	17.5BCD	18ABCD	19.7AB	700DE	654E	743CD	0.19C	0.24B	0.23B	2.27C	2.65C	2.78C	338DE	318EF	357CD	0.52C	0.57C	0.79B
30-60	14.9E	20.1A	18.2ABC	662E	690E	700DE	0.20C	0.15D	0.15D	0.90C	1.28C	0.93C	321EF	300F	322EF	0.29D	0.27D	0.32D
LSD(5%)	2.47			49.1			0.039			2.22			24.1			0.097		

Values followed by the same letter within a parameter are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.10. Effects of interaction of straw management by depth on pre-planting soil chemical properties in the mechanised trial at Asasa

Depth (cm)	P (mg kg <sup>-1</sup> ) 1997			Zn (mg kg <sup>-1</sup> ) 1999		
	Burn	Removal	Retention	Burn	Removal	Retention
0-15	33.7B	40.6A	36.7B	1.19B	1.43A	1.16B
15-30	26.8CDE	28.8CD	29.5C	0.99C	1.07BC	0.75D
30-60	26.3DE	24.7E	27.0CDE	0.41E	0.32EF	0.22F
LSD(5%)	3.01			0.16		

Values followed by the same letter with a parameter are not significantly different at the 5% level of the LSD test.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.11. Effects of interaction of tillage by depth on pre-planting soil chemical properties in the mechanised and ox-plow trials at Kulumsa and Asasa.

Depth	Kulumsa mechanised				Asasa mechanised								Kulumsa ox-plow	
	NH <sub>4</sub> (mg kg <sup>-1</sup> ) 1998		K (mg kg <sup>-1</sup> ) 1999		P (mg kg <sup>-1</sup> ) 1997		NO <sub>3</sub> (mg kg <sup>-1</sup> ) 1998		P (mg kg <sup>-1</sup> ) 1999		K (mg kg <sup>-1</sup> ) 1999		Zn (mg kg <sup>-1</sup> ) 1999	
	CT	ZT	CT	ZT	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT
0-15	11.6AB	13.2A	417A	384B	35.8A	38.1A	39.4A	26.3B	16.6B	19.0A	468A	521A	1.22A	1.17A
15-30	12.9A	10.8BC	348C	327D	28.9B	27.7B	22.7BC	17.1C	10.3C	5.90D	384B	331B	0.97B	0.91B
30-60	10.3BC	9.5C	310D	319D	26.9BC	25.1C	9.5D	6.4D	3.60E	2.70E	378B	377B	0.40C	0.36C
LSD(5%)	1.71		19.7		2.45		5.70		2.10		65.2		0.12	

Values followed by the same letter within a parameter are not significantly different at the 5% level of the LSD test.

CT= Conventional tillage; ZT = Zero tillage, MT = minimum tillage.

P = Mehlich method in 1996 and 1997; P = Olsen method in 1998 and 1999.

Appendix 5.12. Effects of interaction of cropping sequence by depth on pre-planting soil chemical properties in the mechanised trial at and Asasa in 1999

Depth	Asasa mechanised	
	K(mg kg <sup>-1</sup> )	
	Faba bean	Wheat
0-15	450B	539A
15-30	335C	380C
30-60	391BC	364C
LSD (5%)	65.2	

Values followed by the same letters within a parameter are not significantly different at the 5% level of the LSD test.

Appendix 5.13. Effects of interaction of straw management by depth on pre-planting soil chemical properties in the ox-plow trials at Kulumsa and Asasa in 1999.

Depth	Kulumsa ox-plow		Asasa ox-plow	
	K(mg kg <sup>-1</sup> )		K(mg kg <sup>-1</sup> )	
	Burn	Removal	Burn	Removal
0-15	484A	398B	412A	334B
15-30	322C	348C	342B	364AB
30-60	325C	309C	415A	427A
LSD (5%)	48.1		68.3	

Values followed by the same letters within a parameter are not significantly different at the 5% level of the LSD test.

Appendix 5.14. Effect of crop management practices on soil organic matter content (0-5 cm) in the mechanised system trials at Kulumsa and Asasa: ANOVA results.

	Kulumsa mechanised										Asasa mechanised								
	1996		1997		1998		1999		2000	1996		1997		1998		1999		2000	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	
SM (S)	*	**	*	*	NS	*	NS	**	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T)	NS	***	NS	NS	**	†	**	***	**	**	NS	*	NS	NS	NS	NS	NS	NS	NS
S x T	NS	*	NS	NS	NS	NS	NS	*	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
CS (C)	NS	***	*	NS	NS	NS	†	NS	NS	NS	NS	**	NS	NS	NS	NS	†	NS	NS
S x C	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T x C	NS	**	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x T x C	NS	†	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	3.95	3.76	3.99	3.77	3.61	4.49	3.08	3.26	3.10	3.66	4.21	3.41	3.53	3.06	4.11	2.36	2.52	2.34	
C.V.(%)	9.91	5.82	7.28	13.1	3.57	9.27	2.61	5.60	3.92	10.9	4.67	9.57	14.4	8.24	13.8	6.22	5.48	7.87	

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

Pre = Pre-planting (sample taken day of planting); Post = Post harvest (sample taken within 2 days of harvest); SM = Straw management; CS = Cropping sequence.

Appendix 5.15. Effect of crop management practices on soil organic matter content (0-5 cm) in the ox-plow system trials at Kulumsa and Asasa: ANOVA results.

	Kulumsa ox-plow										Asasa ox-plow								
	1996		1997		1998		1999		2000	1996		1997		1998		1999		2000	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	
SM (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T)	NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS
CS (C)	†	*	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x C	NS	*	NS	NS	NS	NS	NS	*	NS	NS	†	NS	NS	NS	†	†	NS	NS	NS
T x C	NS	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	†	NS	NS	NS	NS	NS	NS
S x T x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	3.62	3.95	4.08	3.93	3.77	4.52	2.86	3.08	3.20	3.56	3.85	4.25	3.69	2.86	3.68	2.20	2.33	2.23	2.23
C.V.(%)	11.9	7.44	12.1	9.35	3.63	6.23	2.81	2.80	1.92	8.83	7.21	6.66	10.9	5.02	7.40	6.29	7.43	6.18	6.18

†, \*, \*\*, \*\*\* Statistically significant at  $0.1 < P < 0.05$ ,  $0.01 < P < 0.05$ ,  $0.001 < P < 0.01$  and  $P < 0.001$ , respectively.

Pre = Pre-planting (sample taken day of planting); Post = Post harvest (sample taken within 2 days of harvest); SM = Straw management; CS = Cropping sequence.

Appendix 5.16. Effect of crop management practices on soil organic matter content (0-5 cm) in the mechanised system trials at Kulumsa and Asasa: treatment means.

	Kulumsa mechanised									Asasa mechanised									
	1996		1997		1998		1999		2000	1996		1997		1998		1999		2000	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	
SM (S)																			
Burn	3.65B	3.40B	3.72B	3.47B	3.51	4.33B	3.99	3.04C	3.00B	3.42	4.14	3.28	3.55	2.92	3.92	2.14	2.39	2.31	
Remove	3.91AB	3.91A	3.99AB	3.64B	3.58	4.24B	3.13	3.28B	3.00B	3.57	4.29	3.24	3.46	3.33	4.40	2.47	2.58	2.27	
Retention	4.29A	3.96A	4.29A	4.20A	3.78	4.92A	3.11	3.42A	3.29A	3.99	4.21	3.69	3.57	2.92	4.00	2.47	2.58	2.44	
LSD(5%)	0.32	0.18	0.42	0.36		0.35		0.14	0.23										
Tillage (T)																			
CT	3.85	3.47B	3.96	3.63	3.47B	4.31	2.91B	2.97B	2.89B	3.78A	4.22	3.21B	3.53	3.04	4.06	2.34	2.52	2.29	
ZT/MT	4.05	4.04A	4.03	3.91	3.76A	4.68	3.24A	3.56A	3.31A	3.54B	4.21	3.61A	3.52	3.07	4.15	2.37	2.51	2.39	
CS (C)																			
Faba bean	3.85	3.59B	3.89B	3.72	3.62	4.48	3.05	3.23	3.10	3.60	4.17	3.23B	3.48	3.05	4.06	2.34	2.52	2.32	
Wheat	4.05	3.92A	4.10A	3.82	3.60	4.52	3.10	2.30	3.09	3.72	4.25	3.58A	3.57	3.06	4.16	2.38	2.51	2.36	

Values within a management factor level within a column and followed by the same letter are not significantly different at the 5% level of the LSD test.

Pre = Pre-planting (sample taken day of planting); Post = Post harvest (sample taken within 2 days of harvest); SM = Straw management; CS = Cropping sequence; CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage.

Appendix 5.17. Effect of crop management practices on soil organic matter content (0-5 cm) in the ox-plow system trials at Kulumsa and Asasa: treatment means

	Kulumsa ox-plow									Asasa ox-plow									
	1996		1997		1998		1999		2000	1996		1997		1998		1999		2000	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	
SM (S)																			
Burn	3.62	4.02	4.07	3.82	3.74	4.50	2.80	3.04	3.14	3.48	3.83	4.31	3.83	2.85	3.62	2.19	2.32	2.21	
Remove	3.61	3.88	4.08	4.04	3.81	4.56	2.92	3.12	3.25	3.63	3.87	4.19	3.56	2.86	3.73	2.23	2.34	2.24	
Tillage (T)																			
CT	3.58	3.98	4.02	3.86	3.75	4.39B	2.82	3.05	3.13B	3.54	3.89	4.19	3.89	2.79	3.59	2.17	2.34	2.21	
MT	3.65	3.93	4.13	4.01	3.80	4.67A	2.90	3.12	3.26A	3.58	3.81	4.29	3.49	2.86	3.75	2.24	2.31	2.25	
CS (C)																			
Faba bean	3.42	3.79B	3.93	4.03	3.77	4.46	2.91A	3.06	3.20	3.51	3.85	4.18	3.58	2.87	3.73	2.18	2.34	2.22	
Wheat	3.81	4.11A	4.22	3.84	3.78	4.59	2.80B	3.10	3.19	3.60	3.86	4.32	3.80	2.85	3.62	2.23	2.31	2.24	

Values within a management factor level within a column and followed by the same letter are not significantly different at the 5% level of the LSD test.

Pre = Pre-planting (sample taken day of planting); Post = Post harvest (sample taken within 2 days of harvest); SM = Straw management; CS = Cropping sequence; CT = Conventional tillage; ZT = Zero tillage; MT = Minimum tillage.

Appendix 6.1. Crop management treatment effects on weed seedling population dynamics in wheat in the Kulumsa mechanised trial

Weed species	1993	1994	1995	1996	1997	1998	1999	2000
<i>Wheat variety</i>	Enkoy	Mitike	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa
<i>TBLW/m<sup>2</sup></i>	127.4	64.8	51.0	24.5	46.1	26.5	164	46.6
Straw management (SM)	NS	NS	NS	NS	Ret>Rem, Bu=	Ret>Bu, Rem=	Rem=Ret>Bu	NS
Tillage (T)	NS	ZT>CT	NS	NS	NS	NS	ZT>CT	NS
Cropping sequence (CS)	1 <sup>st</sup> W>CW	NS	---	NS	NS	---	NS	NS
Interaction (I)	NS	NS	NS	T x C	NS	NS	S x T	S x T, S x T x C
<i>TGW/m<sup>2</sup></i>	---	---	24.5	3.91	3.14	6.48	73.3	112.7
SM	---	---	Rem=Ret>Bu	NS	NS	NS	NS	Ret>Rem>Bu
T	---	---	ZT>CT	ZT>CT	NS	NS	ZT>CT	ZT>CT
CS	---	---	---	NS	CW>2 <sup>nd</sup> W	---	NS	CW>2 <sup>nd</sup> W
I	---	---	NS	NS	NS	NS	S x T	S x T x C
<i>Guizotia/m<sup>2</sup></i>	7.74	1.75	1.11	---	1.4	---	2.68	1.52
SM	NS	NS	Ret>Rem, Bu=	---	NS	---	NS	NS
T	NS	NS	NS	---	NS	---	NS	CT>ZT
CS	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW	---	---	NS	---	NS	NS
I	NS	NS	NS	---	NS	---	NS	T x C
<i>Corrigiola/m<sup>2</sup></i>	14.2	3.91	7.34	1.75	3.66	1.06	11.0	2.99
SM	NS	NS	Bu=Ret>Rem	NS	NS	NS	NS	Bu>Rem=Ret
T	CT>ZT	NS	NS	NS	NS	NS	CT>ZT	CT>ZT
CS	CW>1 <sup>st</sup> W	NS	---	NS	NS	---	NS	NS
I	NS	NS	NS	NS	NS	NS	NS	NS
<i>Polygonum/m<sup>2</sup></i>	22.2	2.06	2.88	---	2.22	0.42	---	1.78
SM	Ret>Rem, Bu=	NS	Bu>Rem=Ret	---	NS	Rem>Bu=Ret	---	NS
T	NS	CT>ZT	CT>ZT	---	CT>ZT	NS	---	NS
CS	NS	NS	---	---	NS	---	---	NS
I	NS	NS	NS	---	T x C	NS	---	NS

## Appendix 6.1. Continued

Weed species	1993	1994	1995	1996	1997	1998	1999	2000
<i>Amaranthus/m<sup>2</sup></i>	5.31	1.4	1.60	---	1.49	1.03	1.08	----
SM	NS	Rem>Ret, Bu=	NS	---	NS	NS	NS	----
T	NS	NS	NS	---	CT>ZT	NS	CT>ZT	----
CS	NS	NS	NS	---	NS	---	NS	----
I	NS	NS	NS	---	NS	NS	S x T, T x C	----
<i>Solanum/m<sup>2</sup></i>	21.3	4.79	11.06	7.34	11.2	2.56	4.61	-----
SM	NS	NS	Ret>Rem, Bu=	NS	NS	NS	NS	-----
T	CT>ZT	NS	CT>ZT	NS	ZT>CT	CT>ZT	CT>ZT	-----
CS	NS	NS	---	NS	NS	---	NS	----
I	NS	NS	NS	S x T	NS	NS	NS	-----
<i>Galinsoga/m<sup>2</sup></i>	15.3	7.91	1.54	---	8.02	7.61	92.9	16.8
SM	NS	NS	NS	---	Ret>Rem=Bu	NS	Ret>Bu, Rem=	Ret>Rem=Bu
T	NS	ZT>CT	ZT>CT	---	ZT>CT	ZT>CT	ZT>CT	ZT>CT
CS	1 <sup>st</sup> W>CW	NS	---	---	NS	---	1 <sup>st</sup> W>CW	CW>2 <sup>nd</sup> W
I	NS	T x C	NS	---	NS	NS	S x T	S x T
<i>Bromus/m<sup>2</sup></i>	---	---	---	---	---	---	1.82	29.6
SM	---	---	---	---	---	---	Ret>Bu, Rem=	Ret>Rem>Bu
T	---	---	---	---	---	---	ZT>CT	ZT>CT
CS	---	---	---	---	---	---	NS	NS
I	---	---	---	---	---	---	NS	S x T, T x C
<i>Setaria/m<sup>2</sup></i>	---	---	21.6	1.46	---	1.06	7.02	15.8
SM	---	---	Rem>Ret>Bu	NS	---	NS	NS	NS
T	---	---	ZT>CT	ZT>CT	---	NS	NS	NS
CS	---	---	---	NS	---	---	NS	NS
I	---	---	NS	NS	---	NS	T x C	NS

Mean values detransformed from ANOVA means [i.e., based on  $\text{SQRT}(\text{weed count}/\text{m}^2 + 0.5)$ ].

Bu = Complete burn of crop stubble, Rem= Partial removal of crop stubble, Ret = Complete retention of crop stubble, CT = Conventional tillage, ZT = Zero tillage, CW = Continuous wheat, 1<sup>st</sup> W = 1<sup>st</sup> year wheat after Faba bean, 2<sup>nd</sup> W = 2<sup>nd</sup> year wheat after Faba bean

Appendix 6.2. Crop management treatment effects on weed seedling population dynamics in wheat in the Asasa mechanised trial.

Weed species	1993	1994	1995	1996	1997	1998	1999	2000
<i>Wheat variety</i>	Enkoy	Mitike	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa
<i>TBLW/m<sup>2</sup></i>	68.6	45.7	57.3	60.3	84.7	79.6	59.6	51.5
Straw management (SM)	NS	NS	NS	Rem=Ret>Bu	NS	NS	Rem=Ret>Bu	NS
Tillage (T)	NS	CT>MT	NS	CT>MT	CT>MT	CT>MT	NS	CT>MT
Cropping sequence (CS)	NS	NS	---	1 <sup>st</sup> W>CW	NS	---	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW
Interaction (I)	NS	NS	NS	NS	NS	S x C	NS	S x T
<i>TGW/m<sup>2</sup></i>	---	---	113.9	14.9	28.6	72.7	37.7	187.2
SM	---	---	NS	NS	NS	Ret>Bu, Rem=	NS	Rem>Ret>Bu
T	---	---	NS	NS	NS	MT>CT	NS	MT>CT
CS	---	---	---	CW>1 <sup>st</sup> W	NS	---	NS	CW>2 <sup>nd</sup> W
I	---	---	NS	NS	NS	SxT, SxC, TxC	NS	S x T
<i>Corrigiola/m<sup>2</sup></i>	0.67	12.5	6.26	3.70	12.5	13.6	8.51	3.99
SM	NS	NS	NS	NS	NS	NS	NS	NS
T	NS	NS	NS	CT>MT	CT>MT	NS	NS	CT>MT
CS	NS	NS	---	NS	NS	---	1 <sup>st</sup> W>CW	NS
I	NS	NS	NS	NS	T x C	NS	NS	NS
<i>Guizotia/m<sup>2</sup></i>	8.62	13.4	3.91	5.75	---	2.56	2.80	8.31
SM	NS	NS	NS	NS	---	NS	NS	NS
T	NS	NS	NS	NS	---	MT>CT	MT>CT	NS
CS	NS	NS	---	NS	---	---	NS	NS
I	NS	NS	NS	NS	---	NS	S x T	T x C
<i>Galium/m<sup>2</sup></i>	0.69	13.9	---	---	---	---	---	---
SM	NS	NS	---	---	---	---	---	---
T	NS	CT>MT	---	---	---	---	---	---
CS	NS	NS	---	---	---	---	---	---
I	NS	NS	---	---	---	---	---	---

## Appendix 6.2. Continued

Weed species	1993	1994	1995	1996	1997	1998	1999	2000
<i>Galinsoga/m<sup>2</sup></i>	19.7	---	7.91	28.7	25.3	21.3	9.40	42.1
SM	NS	---	NS	Rem=Ret>Bu	Rem>Bu>Ret	Rem=Ret>Bu	Rem=Ret>Bu	NS
T	NS	---	NS	NS	NS	NS	NS	CT>MT
CS	NS	---	---	1 <sup>st</sup> W>CW	NS	---	1 <sup>st</sup> W>CW	2 <sup>nd</sup> W>CW
I	T x C	---	NS	NS	NS	NS	NS	NS
<i>Solanum/m<sup>2</sup></i>	3.86	1.75	4.38	6.48	11.8	9.36	5.46	4.97
SM	NS	NS	NS	Bu>Rem=Ret	NS	Rem>Bu, Ret=	NS	NS
T	CT>MT	CT>MT	NS	CT>MT	CT>MT	CT>MT	NS	NS
CS	NS	NS	---	NS	NS	---	NS	NS
I	NS	NS	NS	NS	NS	T x C	S x C	S x T
<i>Amaranthus/m<sup>2</sup></i>	7.7	7.74	7.39	330.7	20.5	20.8	9.32	2.85
SM	NS	NS	NS	NS	Ret>Bu, Rem=	NS	NS	NS
T	NS	CT>MT	NS	CT>MT	CT>MT	CT>MT	NS	CT>MT
CS	CW>1 <sup>st</sup> W	NS	---	1 <sup>st</sup> W>CW	NS	---	NS	NS
I	NS	NS	NS	NS	NS	S x C	S x C	S x T x C
<i>Bromus/m<sup>2</sup></i>	---	15.5	6.26	6.26	9.55	30.7	---	148.3
SM	---	NS	NS	NS	Ret=Rem>Bu	Ret=Rem>Bu	---	Rem>Ret>Bu
T	---	MT>CT	NS	MT>CT	NS	MT>CT	---	MT>CT
CS	---	NS	---	CW>1 <sup>st</sup> W	NS	---	---	CW>2 <sup>nd</sup> W
I	---	NS	NS	S x C, T x C	S x C	S x C, T x C	---	S x T
<i>Setaria/m<sup>2</sup></i>	---	---	14.7	2.75	8.20	2.18	9.23	13.4
SM	---	---	Rem>Ret, Bu=	NS	Rem>Bu=Ret	NS	NS	NS
T	---	---	CT>MT	CT>MT	CT>MT	NS	NS	NS
CS	---	---	---	CW>1 <sup>st</sup> W	NS	---	CW>1 <sup>st</sup> W	NS
I	---	---	NS	NS	NS	NS	S x T	NS

Mean values detransformed from ANOVA means [i.e., based on  $\text{SQRT}(\text{weed count}/\text{m}^2 + 0.5)$ ].

Bu = Complete burn of crop stubble, Rem= Partial removal of crop stubble, Ret = Complete retention of crop stubble, CT = Conventional tillage, MT = Minimum tillage, CW=Continuous wheat, 1<sup>st</sup> W = 1<sup>st</sup> year wheat after faba bean, 2<sup>nd</sup> W = 2<sup>nd</sup> year wheat after faba bean

Appendix 6.3. Crop management treatment effects on weed seedling population dynamics in wheat in the Kulumsa ox-plow trial

Weed species	1993	1994	1995	1996	1997	1998	1999	2000
<i>Wheat variety</i>	Enkoy	Mitike	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa
<i>TBLW/m<sup>2</sup></i>	129.6	85.9	48.6	34.3	70.9	42.9	186	56.5
Straw management (SM)	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T)	NS	MT>CT	NS	NS	NS	CT>MT	MT>CT	NS
Cropping sequence (CS)	NS	NS	---	NS	NS	---	NS	NS
Interaction (I)	NS	NS	NS	NS	NS	NS	NS	S x T
<i>TGW/m<sup>2</sup></i>	---	---	14.7	26.5	2.32	4.30	5.40	77.3
SM	---	---	NS	Rem>Bu	Rem>Bu	NS	NS	NS
T	---	---	NS	MT>CT	MT>CT	NS	NS	NS
CS	---	---	---	CW> 1 <sup>st</sup> W	2 <sup>nd</sup> W>CW	---	NS	NS
I	---	---	NS	NS	T x C	NS	NS	NS
<i>Guizotia/m<sup>2</sup></i>	8.26	2.39	2.06	---	0.83	---	5.75	4.65
SM	NS	NS	NS	---	Bu>Rem	---	NS	NS
T	NS	NS	NS	---	NS	---	NS	MT>CT
CS	1 <sup>st</sup> W>CW	NS	---	---	NS	---	CW>1 <sup>st</sup> W	NS
I	NS	S x T	NS	---	NS	---	NS	NS
<i>Corrigiola/m<sup>2</sup></i>	10.85	7.91	5.75	3.83	3.28	1.37	13.3	2.39
SM	NS	Bu>Rem	NS	NS	Rem>Bu	NS	NS	NS
T	NS	MT>CT	NS	NS	MT>CT	CT>MT	NS	MT>CT
CS	CW>1 <sup>st</sup> W	CW>2 <sup>nd</sup> W	---	NS	NS	---	CW>1 <sup>st</sup> W	NS
I	T x C	T x C	NS	NS	NS	S x C	NS	S x T
<i>Polygonum/m<sup>2</sup></i>	1.43	2.06	1.75	0.94	---	---	2.58	1.38
SM	NS	NS	NS	NS	---	---	NS	NS
T	CT>MT	NS	NS	NS	---	---	NS	NS
CS	NS	NS	---	NS	---	---	NS	NS
I	NS	NS	NS	NS	---	---	S x C	NS

## Appendix 6.3. Continued

Weed species	1993	1994	1995	1996	1997	1998	1999	2000
<i>Amaranthus/m<sup>2</sup></i>	2.32	---	1.75	0.5	1.06	---	3.25	----
SM	NS	---	NS	NS	NS	---	NS	----
T	CT > MT	---	NS	NS	NS	---	NS	----
CS	NS	---	---	NS	CW > 2 <sup>nd</sup> W	---	NS	----
I	NS	---	NS	S x T	NS	---	NS	----
<i>Solanum/m<sup>2</sup></i>	34.9	40.5	19.8	4.34	25.4	15.9	12.9	-----
SM	NS	NS	NS	NS	NS	NS	NS	-----
T	NS	NS	NS	NS	MT > CT	CT > MT	NS	-----
CS	NS	NS	---	NS	NS	---	NS	-----
I	NS	NS	NS	NS	NS	NS	NS	-----
<i>Galinsoga/m<sup>2</sup></i>	22.3	7.34	2.39	0.58	4.12	2.81	110	28.9
SM	NS	NS	NS	NS	NS	NS	NS	NS
T	NS	MT > CT	NS	NS	MT > CT	MT > CT	MT > CT	MT > CT
CS	NS	NS	---	NS	2 <sup>nd</sup> W > CW	---	NS	NS
I	NS	NS	NS	NS	NS	NS	NS	NS
<i>Setaria/m<sup>2</sup></i>	---	---	12.46	7.34	---	---	1.14	6.20
SM	---	---	NS	Rem > Bu	---	---	NS	NS
T	---	---	NS	NS	---	---	NS	MT > CT
CS	---	---	---	CW > 1 <sup>st</sup> W	---	---	1 <sup>st</sup> W > CW	NS
I	---	---	NS	NS	---	---	T x C	T x C

Mean values detransformed from ANOVA means [i.e., based on  $\text{SQRT}(\text{weed count}/\text{m}^2 + 0.5)$ ].

Bu = Complete burn of crop stubble, Rem = Partial removal of crop stubble, CT = Conventional tillage, MT = Minimum tillage, CW = Continuous wheat, 1<sup>st</sup> W = 1<sup>st</sup> year wheat after faba bean, 2<sup>nd</sup> W = 2<sup>nd</sup> year wheat after faba bean

Appendix 6.4. Crop management treatment effects on weed seedling population dynamics in wheat in the Asasa ox-plow trial

Weed species	1993	1994	1995	1996	1997	1998	1999	2000
<i>Wheat variety</i>	Enkoy	Mitike	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa	Qubsa
<i>TBLW/m<sup>2</sup></i>	320.9	19.8	13.2	33.17	51.05	49.6	41.5	18.9
Straw management (SM)	NS	NS	Bu>Rem	NS	Rem>Bu	NS	NS	Rem>Bu
Tillage (T)	CT>MT	NS	NS	NS	CT>MT	NS	MT>CT	CT>MT
Cropping sequence (CS)	NS	NS	---	NS	NS	---	NS	NS
Interaction (I)	S x C	NS	S x T	NS	NS	NS	NS	NS
<i>TGW/m<sup>2</sup></i>	---	---	274.6	100.3	24.6	38.4	22.5	181.0
SM	---	---	Rem>Bu	NS	NS	Rem>Bu	NS	Rem>Bu
T	---	---	NS	NS	NS	NS	NS	NS
CS	---	---	---	CW>1 <sup>st</sup> W	NS	---	NS	NS
I	---	---	NS	NS	NS	NS	NS	T x C
<i>Corrigiola/m<sup>2</sup></i>	0.79	3.46	1.22	12.2	8.20	8.92	7.60	4.52
SM	NS	NS	NS	NS	Rem>Bu	NS	NS	NS
T	NS	NS	NS	NS	CT>MT	NS	NS	NS
CS	NS	NS	---	NS	2 <sup>nd</sup> W>CW	---	NS	NS
I	S x C, T x C	NS	NS	NS	NS	NS	NS	NS
<i>Guizotia/m<sup>2</sup></i>	4.03	1.99	---	---	1.43	---	0.97	2.56
SM	NS	NS	---	---	NS	---	NS	NS
T	NS	NS	---	---	NS	---	NS	CT>MT
CS	NS	NS	---	---	NS	---	NS	NS
I	NS	NS	---	---	NS	---	S x T x C	S x T
<i>Galinsoga/m<sup>2</sup></i>	9.74	5.26	2.60	101.1	---	6.68	3.70	1.60
SM	NS	Bu>Rem	Bu>Rem	NS	---	NS	Rem>Bu	NS
T	CT>MT	NS	NS	NS	---	MT>CT	NS	NS
CS	NS	2 <sup>nd</sup> W>CW	---	NS	---	---	1 <sup>st</sup> W>CW	NS
I	NS	NS	NS	NS	---	NS	NS	NS

## Appendix 6.4. Continued

Weed species	1993	1994	1995	1996	1997	1998	1999	2000
<i>Solanum/m<sup>2</sup></i>	4.60	2.88	0.89	0.80	---	3.07	1.71	1.84
SM	NS	NS	NS	NS	---	NS	Rem>Bu	NS
T	NS	NS	NS	NS	---	NS	NS	NS
CS	NS	NS	---	NS	---	---	NS	2 <sup>nd</sup> W>CW
I	NS	NS	NS	NS	---	NS	NS	NS
<i>Amaranthus/m<sup>2</sup></i>	10.19	3.03	2.21	5.75	13.04	5.85	3.55	----
SM	NS	NS	NS	NS	Rem>Bu	NS	NS	----
T	CT>MT	MT>CT	NS	NS	CT>MT	CT>MT	NS	----
CS	NS	NS	---	1 <sup>st</sup> W>CT	CW>2 <sup>nd</sup> W	---	S x T	----
I	NS	NS	S x T	NS	NS	NS	NS	----
<i>Bromus/m<sup>2</sup></i>	---	91.3	154.0	84.3	10.5	---	---	179.5
SM	---	Rem>Bu	Rem>Bu	NS	Rem>Bu	---	---	Rem>Bu
T	---	NS	NS	NS	NS	---	---	NS
CS	---	CW>2 <sup>nd</sup> W	---	CW>1 <sup>st</sup> W	CW>2 <sup>nd</sup> W	---	---	NS
I	---	NS	NS	NS	NS	---	---	T x C
<i>Setaria/m<sup>2</sup></i>	---	---	1.70	0.75	---	---	---	2.42
SM	---	---	NS	NS	---	---	---	NS
T	---	---	NS	NS	---	---	---	CT>MT
CS	---	---	---	CW>1 <sup>st</sup> W	---	---	---	NS
I	---	---	NS	NS	---	---	---	NS

Mean values detransformed from ANOVA means [i.e., based on  $\text{SQRT}(\text{weed count}/\text{m}^2 + 0.5)$ ].

Bu = Complete burn of crop stubble, Rem= Partial removal of crop stubble, CT = Conventional tillage, MT = Minimum tillage, CW = Continuous wheat, 1<sup>st</sup> W = 1<sup>st</sup> year wheat after faba bean, 2<sup>nd</sup> W = 2<sup>nd</sup> year wheat after faba bean

### Appendix 9.1. Frequency of operations in the Kulumsa mechanised trial

Year	Ploughing frequency (no.)	Disk harrow frequency (no.)	Roundup spray frequency <sup>a</sup> (no.)	Roundup application rate <sup>a</sup> (l/ha)
1992 <sup>b</sup>	---	---	---	---
1993	1	1	1	2
1994	1	1	2	2
1995	1	1	2	2
1996	1	1	2	2
1997	2	1	2	2
1998	1	1	2	2
1999	1	1	2	2
2000	1	1	1	3

<sup>a</sup> Herbicide rate and frequency of application were identical for the mechanised and ox-plover trials at Kulumsa.

<sup>b</sup> All pre-plant operations were identical during 1992; thus, the operations and associated costs did not vary among the treatments and were excluded from the partial budget analysis.

### Appendix 9.2. Frequency of operations in the Asasa mechanised trial

Year	Ploughing frequency (no.)	Disk harrow frequency (no.)	Roundup spray frequency <sup>a</sup> (no.)	Roundup application rate <sup>a</sup> (l/ha)
1992 <sup>b</sup>	--	---	---	---
1993	1	1	1	2
1994	1	1	1	2
1995	1	1	1	2
1996	1	1	1	2
1997	1	1	1	2
1998	1	1	1	2
1999	1	1	1	2
2000	1	1	1	2

<sup>a</sup> Herbicide rate and frequency of application were identical for the mechanised and ox-plover trials at Asasa.

<sup>b</sup> All pre-plant operations were identical during 1992; thus, the operations and associated costs did not vary among the treatments and were excluded from the partial budget analysis.

## Appendix W1. Precipitation (mm) and temperature (°C) characteristics during the period of conducting the experiment at Kulumsa

Character	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sowing date (SD)	1/7	7/7	7/7	30/6	26/6	26/6	29/6	22/6	4/7
Precipitation SD-15→-11	8.8	3.1	29.4	17.9	25.0	23.3	6.5	8.8	3.8
Precipitation SD-10→-6	4.0	7.4	48.4	6.9	37.0	18.8	17.6	29.9	71.0
Precipitation SD-5→-1	10.6	10.2	25.1	34.0	3.6	3.7	58.5	5.5	54.0
Precipitation SD 0→+4	35.6	8.6	29.2	6.9	6.3	53.0	0.3	7.5	8.5
Precipitation SD+5→+9	21.7	36.7	7.9	43.3	11.5	30.1	1.8	29.6	51.7
Precipitation SD+10→+14	11.0	3.2	12.2	31.4	20.5	19.9	9.0	7.9	31.6
Precipitation SD+15→+19	3.1	26.2	27.8	14.3	8.6	13.2	14.0	29.7	28.6
Precipitation SD-15→-1	23.4	20.7	102.9	58.8	65.6	45.8	82.6	44.2	128.8
Precipitation SD 0→+19	71.4	74.7	77.1	95.9	46.9	116.2	25.1	74.7	120.4
Seasonal precipitation	576	497	540	418	449	572	616	581.1	564
Annual precipitation	809	931	713	861	880	937	878	746.6	787.4
Mean Tmax during season	21.3	21.5	21.8	21.9	22.5	21.8	21.6	21.3	21.3
Mean Tmin during season	11.4	11.3	11.9	11.9	11.2	11.1	10.3	11.8	11.9

The growing season covers from June- November

Appendix W2. Precipitation (mm) and temperature (°C) characteristics during the period of conducting the experiment at Asasa.

Character	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sowing date (SD)	19/6	17/6	17/6	16/6	13/6	12/6	11/6	11/6	16/6
Precipitation SD-15→-11	8.3	0.5	24.3	7.0	1.2	11.1	1.4	1.6	15.2
Precipitation SD-10→-6	6.2	13.5	15.2	1.4	16.1	8.7	8.7	12.2	12.7
Precipitation SD-5→-1	4.0	0.4	36.1	0.9	15.7	0	3.1	0.0	6.4
Precipitation SD 0→+4	4.6	7.9	26.5	5.7	16.8	12.0	11.7	22.2	0.8
Precipitation SD+5→+9	16.7	19.5	43.8	0	6.6	40.7	0	3.1	22.4
Precipitation SD+10→+14	25.3	22.4	14.7	21.2	22.8	10.0	35.4	30.7	16.3
Precipitation SD+15→+19	20.6	15.9	14.2	12.4	1.3	52.7	44.0	59.4	29.3
Precipitation SD-15→-1	18.5	14.4	75.6	9.3	33.0	19.8	13.2	13.8	34.3
Precipitation SD 0→+19	67.2	65.7	99.2	39.3	47.5	115.4	91.1	115.4	69.3
Seasonal precipitation	555	449	641	397	509	429	515	559.2	478
Annual precipitation	752	735	723	638	737	574	706	714.7	555
Mean Tmax during season	22.8	22.9	22.0	23.5	23.9	23.0	22.1	22.1	22.7
Mean Tmin during season	7.4	6.8	6.6	6.6	6.5	7.2	8.7	7.7	7.4

The growing season covers from June- November

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