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The effects of several crop management systems on bread wheat yields in the Ethiopian highlands

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ABSTRACT

Crop management (CM) research conducted in Ethiopia has tended to quantify yield gains and losses associated with single management factors, making it difficult to determine the relative importance of main effects and interactions among factors. During 1987 and 1988, exploratory trials examining several CM factors for bread wheat (*Triticum aestivum*) production were conducted at four research centres situated in the priority wheat production zones of Ethiopia. In the two cropping seasons of 1990, five similar trials were executed in south-eastern Ethiopia to examine the differential responses to four CM factors between farmers' fields and a research site. All 13 trials examined differences between local and improved bread wheat varieties, and response to fertiliser and hand weeding. A fourth factor of local significance such as fungicide, insecticide, or sowing date was added at each site to complete a 24 design. Treatment main effects exerted the predominant influence on grain yield (GY). Relative to unimproved traditional germplasm, GY increments from modern varieties ranged from 13 to 315%. Fertiliser application reduced GY by 9% in one trial due to enhanced lodging, but, in nine others, increased yield from 20 to 88%. Hand weeding increased GY in nine trials; the increases ranged from 17 to 94%. Fungicide increased GY by 5% in two trials, primarily by increasing the yield of a susceptible semi-dwarf variety under a heavy epidemic of stripe rust (*Puccinia striiformis*). Seed treatment with insecticide for control of shoot fly (*Delia arambourgi*) increased GY by 13 to 46% in four trials. Two way interactions involving variety emphasised the greater responsiveness of modern varieties to improved management and higher levels of inputs. Overall, the interactions demonstrated the beneficial impact of combining improved production practices in one cultural package. From the comparison of on-farm and on-station results, it was apparent that station conditions differ dramatically from farmers' circumstances in terms of heat crop response to hand weeding, fertiliser application and insecticidal seed treatment. This has obvious implications for the extrapolation of research results generated on station to the surrounding small-scale farming community.

Key Words: Fertiliser, fungicide, herbicide, improved variety, insecticide, shoot fly, sowing date

RESUME

En Ethiopie, les recherches menees sur la relation pratiques culturales-rendement reposent en general sur une analyse monofactorielle. L'importance relative des effets d'interaction entre les facteurs est par consequent difficile a evaluer. Des essais exploratoires ont ete menes en 1987 et 1988 dans quatre centres de recherche ethiopiens localises dans les zones de production prioritaire de ble; ces essais avaient pour objectif d'etudier l'impact de plusieurs composantes de l'itineraire technique sur le rendement en grains du ble tendre (*Triticum aestivum*). Pendant les deux cycles de culture de l'annee 1990, cinq dispositifs experimentaux identiques ont ete mis en place dans le sud-est ethiopien afin d'observer la variabilite de reponse en conditions paysannes et en station, pour quatre composantes de l'itineraire technique. Dans les 13 cas, on a considere les differences entre les varietes locales et les varietes ameliorees de ble tendre, ainsi que la reponse a la fertilisation et au desherbage manuel. Le quatrieme facteur a ete selectionne en fonction de sa pertinence locale: selon les sites, il pouvait s'agir de l'emploi du fongicide, d'insecticide, ou encore de la date de semis. Dans tous les cas, on a obtenu un schema 24. Les resultats montrent que ce sont les effets directs qui ont le plus d'impact sur le rendement en grains (RG). Les rendements obtenus avec des varietes ameliorees ont ete superieurs a ceux obtenus avec des cultivars traditionnels, le differentiel variant de 13 a 315%. L'application d'engrais a conduit dans un cas a une reduction du RG de 9%, en raison d'une aggravation de la verse; dans neuf autres cas, cependant, les RG ont connu une augmentation allant de 20 a 88%. Le desherbage manuel a induit une augmentation de RG allant de 17 a 94%. L'application du fongicide a conduit a une augmentation de RG de 5% dans deux essais, ce qui correspond essentiellement a l'amelioration du contr“le phytosanitaire d'une variete semi-naine sensible dans le contexte d'une forte pression de rouille jaune (*Pccinia striiformis*). Le traitement insecticide des semences pour le contr“le de la mouche de la tige (*Delia arambourgi*) a conduit a une augmentation de RG allant de 13 a 46% dans quatre essais. La mise en evidence, pour le facteur variete, d'effets d'interaction 2 a 2 avec les autres facteurs souligne le potentiel de reponse des varietes modernes superieur a l'amelioration de l'itineraire technique et a des niveaux eleves d'intrants. De maniere plus generale, la mise en evidence d'interactions demontre l'interet d'une approche en termes de combinaison des pratiques culturales ameliorees. Il ressort de la comparaison des resultats en conditions paysannes et en station que les conditions de production sont extremement differentes dans un cas comme dans l'autre. Cela se traduit par la variabilite des reponses en termes de RG au desherbage manuel, a l'application d'engrais, et au traitement insecticide des semences. Il est important de prendre cette donnee en compte si l'on cherche a extrapoler les resultats obtenus en station au contexte de la production paysanne environnante.

Mots Cles: Date de semis, engrais, fongicide, herbicide, insecticide, mouche de la tige, variete amelioree

INTRODUCTION

Constraints to the realisation of potential grain yield (GY) in any particular agro-ecological zone consist of a number of factors (Nilson and Juhnke, 1984). In an environment such as the central highlands of Ethiopia, where moisture is relatively non-limiting, reported constraints to bread wheat (*Triticum aestivum* L.) production include inappropriate varietal selection, poor weed control, low soil macronutrient and/or micronutrient levels, inappropriate seeding date and rate, poor seedbed preparation, and inadequate crop protection technology (Tanner *et al.*, 1991; Tanner and Giref, 1991). Several of these factors have been identified as major constraints to bread wheat production at the peasant farmer level in farming system surveys in Ethiopia (Aleligne and Franzel, 1987; Alemayehu and Franzel, 1987). Weed competition has been reported to reduce wheat yields by up to 36% (Rezene, 1985). Breakdown of varietal resistance to, in particular, the rust diseases (*Puccinia* spp.) has seriously hampered wheat production by peasant farmers in Ethiopia (Bekele and Tanner, 1995). In the Sinana district of Bale Region in southeastern Ethiopia, constraints to bread wheat production at the peasant farm level include a high density of insect pests of wheat (e.g., *Delia arambourgi*, barley shoot fly; *Diuraphis noxia*, Russian wheat aphid) (Alemayehu and Franzel, 1987).

Historically, crop management (CM) trials conducted in Ethiopia dealt with single factors (Hailu *et al.*, 1988), but in the mid - late 1980s, commodity researchers began conducting more comprehensive multi-factor trials to examine the interactions among various factors (Alem *et al.*, 1990; Nigussie and Mesfin, 1994). This paper summarises the results of 13 multi-factor CM trials conducted on bread wheat in Ethiopia. Eight trials were conducted at four government-funded research centres during 1987 and 1988, and five trials were situated on-farm and on-station in Sinana district in southeastern Ethiopia in 1990. Each trial examined the main effects of varietal differences, fertiliser application, and hand weeding on wheat GY, and the interactions among these factors. A fourth factor such as fungicide, insecticide, or sowing date, indicated as being of local importance, was added at each site, resulting in a total of four factors. Concurrent evaluation of response to CM factors on farmers' fields and on-station was conducted to evaluate the representativeness of research station conditions.

MATERIALS AND METHODS

Experiment I. Multi-factor CM trials were conducted during 1987 and 1988 at four government-funded research stations representing the high potential zones for bread wheat production in the northwestern, central and southeastern highlands of Ethiopia. Characteristics of the four stations are listed in Table 1. The Adet and Sinana stations were newly established in late 1986.

TABLE 1. Characteristics of the four research stations participating in the crop management study on bread wheat in Ethiopia

Site	Latitude (N)	Longitude (E)	Altitude (m a s l)	Annual rainfall (mm)	Soil	
					Classification^a	Texture

Kulumsa	8^o02'	39^o10'	2200	824	Intergrade^b	Clay loam
Holetta	9^o03'	38^o30'	2400	1086	eN	Clay
Adet	11^o17'	37^o43'	2240	1303	eN	Clay
Sinana	7^o07'	40^o10'	2400	851	pV	Clay

^a eN, pV = eutric Nitosol, pellic Vertisol
^b Intergrade between luvic Phaeozem and eutric Nitosol
^o degrees

Each trial was repeated for two seasons at the same station. At Kulumsa, Holetta and Adet stations, the trials were conducted in 1987 and 1988, but at Sinana, located in a zone receiving bimodally-distributed rainfall, the two growing seasons of 1988 were used for the trial.

The experimental design used at all sites except at Adet was a 2^4 factorial in randomised complete blocks with three replications; CM factors included in the trials (Table 2) consisted of zone-specific recommendations versus farmers' practices for wheat variety, fertiliser application and hand weeding. In each zone, these three factors were combined with a fourth factor of local significance. At the Adet site, sowing date comprised a main plot factor within replications and the subfactors were randomised as subplots within sowing dates. At the other three sites, all 16 treatments were unrestricted in randomisation within replications.

TABLE 2. Factors studied at the recommended (+) and farmers' (-) levels in the crop management study on bread wheat in Ethiopia

Sites (Sowing dates)	Factors	Factor levels	
		Recommended (+)	Farmers' (-)
Experiment I			
Kulumsa	Variety	Dashen	Enkoy
(01/07/87 and	Fertiliser	60-26a	nil
02/07/88)	Hand weeding	twice	nil
	Fungicide	triademefon^b	nil
Holetta	Variety	Dashen	Enkoy
(24/06/87 and	Fertiliser	60-26a	nil
26/06/88)	Hand weeding	once	nil
	Fungicide	triademefon^b	nil
Adet	Variety	Dashen	Israel
(see factor level)	Fertiliser	60-26a	nil
	Hand weeding	twice	nil
	Sowing date	June 16	July 16
Sinana	Variety	Dashen	Wollandi
(01/03/88 and	Fertiliser	60-26a	nil
17/07/88)	Hand weeding	twice	nil
	Insecticide	aldrin^c + malathion^d	nil
Experiment II			
Sinana	Variety	ET13	Wollandi
(7-10/03/90 and	Fertiliser	41-20a	nil
10-12/07/90)	Hand weeding	twice	nil
	Insecticide	aldrin^c	nil

^a Rate of N-P in kg ha^-1 from urea and triple super phosphate, respectively
^b Applied once at crop flag leaf emergence at the rate of 0.5 kg a.i. ha^- 1 from Bayleton^R (a product of Bayer AG)
^c Applied as seed dressing at 2 g a.i. kg-1 of seed from Aldrex^R (a product of Shell Chemical Co.)
^d Applied once as foliar spray at crop flag leaf emergence at 300 g a.i. ha^-1 from Carbophos^R (a product of American Cyanamid)

Individual plot sizes were 2.2 x 5 m (= 11 m^2) with a row spacing of 20 cm. Seed rate was 150 kg ha^-1. Seeds and fertilisers were applied in rows constructed manually using a row marker. Fertilisers were applied first and mixed with soil in the row, then seeds were sown and covered with soil. Seeds and fertilisers were sown as early as possible each season (i.e., when the soil was moderately moist), except at Adet where sowing date was an experimental variable fixed as June 16 and July 16. Sowing dates for all other trials are listed in Table 2. Seedbeds at all research sites had been prepared according to conventional tillage practice (i.e., primary tillage by mouldboard plough followed by disk harrowing). For plots weeded twice, hand weeding was carried out from 15 to 20 days and again at 35 to 40 days after crop emergence; single weedings were applied from 25-30 days after crop emergence.

In all trials, the crop was harvested close to the soil surface using a sickle, enabling determination of grain, biomass, and straw yields and harvest indices.

Individual site GY data were analysed using a random linear additive model (Steel and Torrie, 1960).

Experiment II. In both cropping seasons of 1990, a series of trials were established in Sinana district in southeastern Ethiopia to examine the differential effects of four CM factors in trials established concurrently on farmers' fields and on the research centre. Three trials were established in the first crop season ("Belg" from March to June) and in the second crop season ("Meher" from July to November) of 1990. During each season, two of the trials were sown on selected farmers' fields within 10 km of the Sinana Research Centre (SRC) and one trial was sown on SRC's research fields. Host farmers were selected on the basis of being representative wheat producers, and having expressed a willingness to host an on-farm trial. The farmers' fields varied in texture from sandy loams to loamy clays.

For the 1990 trials, the experimental design used, a 2^4 factorial in randomised complete blocks with three replications, was identical to that of Experiment I. Crop management factors included in the trials (Table 2) consisted of zone-specific recommendations versus farmers' practices for wheat variety, fertiliser application, hand weeding and insecticidal seed dressing. Relative to Experiment I, the improved bread wheat variety ET13 was substituted for the semi-dwarf Dashen (Table 2) which had broken down to stripe rust in 1987-88 as reported by Bekele and Tanner (1995). Fertiliser application rate was also modified in 1990 to reflect revised zone-specific recomme-ndations (Amanuel *et al.*, 1991).

In 1990, plot sizes were modified to compensate for the greater heterogeneity of farmers' fields. The gross plot size used was 5 x 5 m. On farmers' fields, seed was broadcast at the rate of 150 kg ha^-1, and then was incorporated (with or without fertiliser, according to treatment) by one pass of the local ox-plough. In the on-station trials, seed was broadcast and subsequently incorporated by hand hoes according to normal station practice. The seedbed at each farm site had been prepared by ox-plough according to the host farmer's conventional practice, while the research station staff prepared land using a mouldboard plough followed by a disc harrow for secondary tillage. A net plot of 9 m^2 was harvested close to the soil surface using a sickle, enabling determination of grain, biomass and straw yields and harvest index. One of the on-farm trials in the "Meher" season of 1990 was harvested prematurely by the host farmer, and was excluded from further analysis.

Individual site data were analysed using a random linear additive model (Steel and Torrie, 1960). Subsequently, Sinana trial data from 1990 were combined for analysis, grouping together on-farm and on-station trials.

RESULTS AND DISCUSSION

Experiment I. Trial yields reflected the yield potential associated with each environment, with Kulumsa exhibiting the highest mean wheat grain yields of 4,864 and 4,010 kg ha^-1 in 1987 and 1988, respectively (Tables 3 and 4). Trial C.V.s were within an acceptable range at all sites except Adet; there the high C.V.s in both 1987 and 1988 reflected the relatively heterogeneous field conditions at this newly established (i.e., 1986) research centre. For each station, year by treatment interaction was significant, necessitating the presentation of results by individual trial.

Differential response to almost all of the CM factors tested (i.e., varieties, fertiliser, hand weeding, fungicides, and insecticide) across sites and between seasons within sites was apparent. Concerning treatment main effects, variety, hand weeding, and fertiliser had a significant impact on wheat GY in 7, 7, and 6 of the 8 trials, respectively. Fungicide (2 of 4), insecticide (1 of 2), and sowing date (0 of 2) had less effect in those trials in which they were included. Of the six two-way factor interactions measured in each trial, the number of significant interactions ranged from 0 to 3 (Tables 3 and 4). The relative unimportance of interaction effects on GY can be seen by comparing the sums of each of the four main effects in each trial with the difference between the two treatments having all factor levels + or - in the same trial; only at Holetta and Adet in 1987 did these two values differ by more than 300 kg ha^-1. Specific interactions from Experiment I will be discussed in a subsequent section in conjunction with those from Experiment II.

TABLE 3. Effects of crop management factors on bread wheat grain yield (kg ha^-1) and absolute yield range at Kulumsa and Holetta in 1987 and 1988

Factor		Kulumsa		Holetta	
		1987	1988	1987	1988
Variety (V)	-	4476	3824	2453	2018
	+	5260	4195	2216	1665
Main effect		+784	+371	-237	-353
	P	***	**	**	**

Fertiliser (F)	-	4803	4200	1622	1320
	+	4933	3820	3047	2362
Main effect		+130	-380	+1425	+1042
	P	NS	**	***	***
Weeding (W)	-	4210	3690	2031	1737
	+	5527	4330	2638	1945
Main effect		+1317	+640	+607	+208
	P	***	***	***	NS
Fungicide (Fu)	-	4760	3903	2280	1752
	+	4977	4116	2389	1930
Main effect		+217	+213	+109	+178
	P	*	P<0.1	NS	NS
All factors -		3835	3742	1717	1481
All factors +		6275	4543	3918	2751
% change		+64	+21	+128	+86
Interactions		V x W *	V x W *	F x W *	
			V x Fu *	F x Fu *	
				W x Fu *	
Mean		4864	4010	2334	1841
C.V.(%)	7.5 9.6	12.9	20.1		

*, **, ***: Significant at the 5, 1 and 0.1% level of probability, respectively
NS: Not significant

TABLE 4. Effects of crop management factors on bread wheat grain yield (kg ha^-1) and absolute yield range at Sinana and Adet in 1987 and 1988

Factor		Sinana 1988 Belg	Sinana 1988 Meher	Factor	Adet 1987	Adet 1988
Variety (V)	-	1499	1187	V:-	677	1184
	+	1911	2154	+	2808	1503
Main effect		+412	+967		+2131	+319
	P	***	***		***	NS
Fertiliser (F)	-	1492	1517	F:-	1618	934
	+	1918	1824	+	1867	1753
Main effect		+426	+307		+249	+819
	P	***	**		NS	***
Weeding (W)	-	1459	1515	W:-	1185	1158
	+	1951	1825	+	2300	1529
Main effect		+492	+310		+1115	+371
	P	***	**		***	P<0.1
Insecticide (I)	-	1628	1471	Sa:-	1523	1513
	+	1782	1869	+	1963	1174
Main effect		+154	+398		+440	-339
	P	NS	***		NS	NS
All factors -		1181	630	All -	150	696
All factors +		2700	2729	All +	4452	1923
% change		+129	+333		+2868	+176
Interactions		V x F P<0.1	V x I P<0.1		V x W *	F x S *
		V x W *				
Mean		1705	1670		1743	1343
C.V.(%)		21.8	23.1		57.5	50.6

^a Sowing date
*, **, ***: Significant at the 5, 1 and 0.1% level of probability, respectively
NS: Not significant

Variety. The variety Dashen, released commercially in 1984 in Ethiopia, is a high yielding, input responsive, semi-dwarf selected from the "Veery" germplasm originating from Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT). At two sites, Kulumsa and Holetta, Dashen was compared to the older variety Enkoy, released in 1973 in Ethiopia; at the remaining two sites, Dashen was compared to unimproved farmers' germplasm (i.e., Israel at Adet, Wollandi at Sinana).

Dashen consistently outyielded the older Ethiopian variety Enkoy at Kulumsa; the yield differential was 18 and 10% in 1987 and 1988, respectively. However, at Holetta, Enkoy outyielded Dashen in both seasons; the difference was 10% and 18% in 1987 and 1988, being exactly the same magnitude of GY difference as at Kulumsa, but in favour of Enkoy. There is no obvious explanation for this reversal of yield performance, but it must reflect specificity of adaptation of the bread wheat varieties released in Ethiopia (Bekele and Tanner, 1995).

Comparing Dashen to the local awnless, tall and unimproved farmers' varieties revealed significantly higher GY for Dashen in 3 of the 4 trials; Dashen outperformed Wollandi at Sinana by 27 and 81% in the 1988 "Belg" and "Meher" seasons, respectively, while at Adet in 1987, Dashen outyielded Israel by 315%.

Weeding. The main effect of hand weeding was significant and positive in 7 of 8 trials; GY increments ranged from 17 to 94% across the 8 trials.

At Kulumsa, the GY increment due to hand weeding represented 31 and 17% of the unweeded check in 1987 and 1988, respectively. Response to hand weeding at Holetta was also quite high in 1987, resulting in a 30% yield increase. At Sinana, the main effect of weeding increased GY in the "Belg" and "Meher" seasons by 34 and 20%, respectively; farmers report that the "Belg" season is usually associated with the highest level of weed infestation (Alemayehu and Franzel, 1987). At Adet, hand weeding increased GY significantly by 94 and 32% in 1987 and 1988, respectively.

Fertiliser. Fertiliser effect was significant in 6 of 8 trials. At Kulumsa there was no GY response to fertiliser in 1987 and a negative response in 1988: 60 kg N plus 26 kg P ha^-1 reduced GY by 380 kg ha^-1 or 9% relative to the 0-0 check. The lack of response to fertiliser in 1987 was consistent with reports over the past decade indicating a lack of response to either N or P on the Kulumsa station (Tanner *et al.*, 1991), due to high historic rates of fertilisation and the rotation with leguminous crops practised on the centre's fields. Thus, it is not possible to extrapolate the fertiliser response from this trial to neighbouring farmers' fields where response to N and P has been consistently positive (Amanuel *et al.*, 1991). In 1988, the negative GY response to fertiliser was due to enhanced lodging during heavy rains late in the season.

Response to fertiliser at Holetta was positive and high in both years. Yield increases due to fertiliser application were 88 and 79% in 1987 and 1988, respectively, representing conversion ratios of 16.6 and 12.1 kg grain per kg nutrient.

At Sinana, GY response to fertiliser was positive in both seasons; GY increased by 29 and 20%, respectively, in the 2 seasons, due to the application of 60 kg of N and 26 kg of P ha^-1. The grain conversion ratio was quite low, however, being 5.0 and 3.6 kg grain per kg nutrient in the "Belg" and "Meher", respectively. This low conversion efficiency suggested that the fertiliser level applied may not have been optimal for this zone, and recommendations were subsequently adjusted for the 1990 trials (Table 2), based on concurrent on-farm N by P trials (Amanuel *et al.*, 1991; Zewdu and Tanner, 1994).

At Adet, the fertiliser effect on GY was significant only in 1988, increasing yield by 88%. The lack of response to fertiliser in 1987 may have been associated with the early-season flooding which deposited large amounts of eroded sediment on the trial area.

Fungicide. The effect of fungicide on GY was significant in 2 of 4 trials. In 1987 at Kulumsa, despite low observed levels of foliar pathogens, triademefon produced a 217 kg ha^-1 or 5% increase in GY. This was probably a result of the "stay green" effect exerted by triademefon on leaf tissue due to its cytokinin-like properties (E. Saari, pers. comm.).

In Ethiopia in 1988, there was a serious epidemic of stripe rust (Puccinia striiformis), consisting primarily of the race virulent to the resistance gene Yr9 carried by Dashen and related wheat varieties (Bekele and Tanner, 1995). Thus, Dashen was severely affected in the trial at Kulumsa in 1988, and mean wheat grain yield was increased by fungicide (P=0.065). Variety by fungicide interaction was significant at the P=0.05 level: the GY of Dashen was increased by 455 kg ha^-1 or 11% by the application of triademefon, while the GY of the rust-resistant variety Enkoy was unaffected by fungicide.

Although the main effect of fungicide on GY was non-significant at Holetta in both seasons, fungicide by fertiliser and fungicide by weeding effects were both significant at Holetta in 1987. With fungicide applied, fertiliser efficiency improved, resulting in a conversion ratio of 18.6 kg grain per kg nutrient vs. 14.5 without fungicide (data not shown). For hand weeded treatments, there was a significant GY increase in response to fungicide application, whereas without weeding there was no response to fungicide. Both interactions demonstrate synergism of CM inputs.

Insecticide. The effect of aldrin insecticide on wheat GY was only significant in 1 of 2 trials at Sinana; during the "Meher" season of 1988, which usually has a higher incidence of barley shoot fly, D. arambourgi (Alemayehu and Franzel, 1987); GY was increased by 398 kg ha^-1 or 27% by aldrin.

Sowing date. The fact that sowing date had no significant effect on GY at Adet in both seasons was probably due to its inclusion as a main plot factor in the experimental design: the F test for sowing date had only 1 and 2 d.f. for error, making it virtually impossible to detect differences. In 1987, the first sowing date appeared to outperform the second (1963 vs. 1523 kg ha^-1) due to flooding caused by heavy rains soon after the second sowing. In 1988, the first sowing date was affected by a prolonged dry spell immediately following sowing (1174 vs. 1513 kg ha^-1). Sowing date by fertiliser response interaction was significant in 1988: the grain to nutrient conversion ratio for the June 16 sowing was negative while for July 16 the conversion ratio was 6.6 kg grain per kg nutrient (data not shown). Thus, the optimum sowing date changed from year to year according to climatic patterns.

Experiment II. In the trials conducted in Sinana district in 1990, wheat GY averaged 2075 kg ha^-1 on-station and 2396 kg ha^-1 on farmers' fields (Table 5). Visual observation of the trials prior to harvest suggested that both weed competition and crop damage by barley shoot fly were much more severe on-station compared to the on-farm situation. On farmers' fields, fertiliser response was more apparent.

TABLE 5. Effects of crop management factors on bread wheat grain yield (kg ha^-1) and absolute yield range on-station and on farmers' fields at Sinana in 1990

Factor		On-station^a	On-farm^b
Variety (V)	-	1980	2122
	+	2169	2671
	Main effect	+189	+549
	P	*	***
Fertiliser (F)	-	2052	2098
	+	2097	2695
	Main effect	+45	+597
	P	NS	***
Weeding (W)	-	1676	2413
	+	2473	2380
	Main effect	+797	-33
	P	***	NS
Insecticide (I)	-	1815	2288
	+	2336	2505
	Main effect	+521	+217
	P	***	NS
All factors -		1385	1707
All factors +		2774	3000
% change		+100	+76
Interactions:		V x W **	
		F x W *	
		W x I *	
		F x I P<0.1	
Mean		2075	2396
C.V.(%)		20.9	24.0

^a Mean of 2 trials (i.e., one in each season)
^b Mean of 3 trials (i.e., two in first season and one in the second season)
*, **, ***: Significant at the 5, 1 and 0.1% level of probability, respectively
NS: Not significant

For combined analysis, the data from the on-station trials were grouped together across seasons, and the same was done for the on-farm trials. Trial seasons were considered as a fixed factor for the purpose of this analysis (i.e., the trials sampled fixed seasons - "Belg" and "Meher"). Analysis of the GY data confirmed the visual observation of the differential impact of the various CM factors on-station and on-farm.

Grain yield response to fertiliser (41 kg N and 20 kg P ha^-1) was significant in all on-farm trials, but was only marginally significant (P<0.1) on-station during one ("Meher") season; the mean on-farm GY response to fertiliser was 597 kg ha^-1

(Table 5) or 28%. The on-farm grain to nutrient conversion ratio of 9.8 kg grain per kg nutrient was similar to that reported by Zewdu and Tanner (1994), representing an improvement in conversion efficiency vis-a-vis that observed in Experiment I; presumably, this reflected the usage in the 1990 trials of a recommended nutrient rate determined from prior on-farm fertiliser trials (Amanuel et al., 1991).

The main effect of hand weeding was non-significant in all of the on-farm trials, but was highly significant in the on-station trials, increasing GY by 48% (Table 5). Presumably, this reflects the build-up of weed populations on-station due to high rates of fertiliser application in previous years and suboptimal control of weeds.

The effect of aldrin seed treatment for the control of barley shoot fly was highly significant on-station in both seasons, increasing GY by 29%. However, seed dressing had a marginally significant effect ($P<0.1$) on GY in only one on-farm trial, and the effect was non-significant in the combined analysis (Table 5).

The improved bread wheat variety ET13 significantly outyielded the tall, local farmers' variety, Wollandi, in all trials except the on-station trial during the "Meher" season. The mean GY increment with ET13 was 26% on farmers' fields, and only 10% on-station. This differential response was due to the higher level of weed infestation on-station, and the inability of ET13 to compete with weeds as effectively as the taller, unimproved variety as reported by Tanner *et al.* (1995). When combined with hand weeding, ET13 outyielded Wollandi by greater margins in the on-station trials.

Comparing the response of wheat GY to the four CM factors on-farm and on-station suggested that research station circumstances differ dramatically from the farmers' situation in terms of wheat response to hand weeding, fertiliser application, and insecticidal seed treatment (Fig. 1). This has obvious implications for the extrapolation of research results generated on-station to the surrounding small-holder farming community, and emphasises the importance of on-farm agricultural research in Sinana district since the research station does not appear to be representative of farmers' conditions.

Figure 1 - Incremental effects of crop management factors on bread wheat grain yield on-station in the Sinana district of Ethiopia in 1990.

The absence of a fertiliser response on-station can be explained by the use of high levels of fertiliser on the centre site since its establishment in 1986. The relatively high weed population on the station may reflect partly its elevated level of soil fertility, but may also suggest the need to reduce weed numbers. The effect of the shoot fly on-station suggests that some aspect of CM renders the station's wheat trials more susceptible to attack by the insect; perhaps the depth of sowing and the seed covering method used on-station result in a shallow crown depth, rendering the plant more susceptible to attack by the shoot fly. Overall, agricultural researchers must be cautious in extrapolating results from the station to farmers' fields.

Contrasting the magnitude of the yield increment when "improved" levels of all four CM factors were applied simultaneously with the sum of the four individual main factor effects indicates that interaction effects had a relatively insignificant impact on wheat GY. For the on-station trials (Table 5), the sum of the main effects was 1552 kg ha^-1 compared to a difference of 1389 kg ha^-1 between the control and the treatment consisting of improved levels for each factor (i.e., +All). On-farm, the corresponding values were 1330 and 1293 kg ha^-1.

The results suggest that small-holders' wheat yields could be increased by over 70% in Sinana district by introducing seed of a recently released variety, and applying N and P fertiliser; the use of seed treatment to control barley shoot fly was not warranted by the on-farm response.

Interactions

The most common, significant two-way factor interactions are discussed in the sections that follow. In most cases, the interactions demonstrate the beneficial impact on wheat GY of simultaneously combining improved production practices in one cultural package (i.e., improved variety + fertiliser + weed control).

Variety by weed control. There were five instances of significant variety by weed control interaction across Experiments I and II; three representative cases are included in Table 6. In all five instances, the highest GY was obtained with the improved variety combined with hand weeding. In each case, with hand weeding, the improved variety was higher yielding than the check (V-) variety; without weeding there was no difference between the two varieties in 3 of 5 cases as in the Sinana 1988 "Belg" trial (Table 6). In all 5 cases, the GY of V+ responded positively to weeding, but in 2 trials, Sinana 1988 "Belg" and Adet 1987, V- did not respond to weed control (Table 6). Thus, both the semi-dwarf variety Dashen and the improved variety ET13 were more responsive to improved management of weeds than the older tall varieties, in agreement with another report of the differential ability of Ethiopian wheat cultivars to compete with weeds (Tanner *et al.*, 1995). Conversely, the improved varieties exhibited a more pronounced suppression of their greater potential yield under conditions of weed competition.

TABLE 6. Effects of interaction of bread wheat variety by weed control on grain yield (kg ha^-1)

	Kulumsa 1987		Sinana 1988B		Adet 1987	
Weed control	-	+	-	+	-	+
Variety:						
^a	3946	5004	1363	1636	550	803
+	4459	6047	1555	2266	1821	3798
LSD (P=0.05)	306		310		835	

^a Varieties listed in Table 2

Fertiliser by weed control. The trials at Holetta in 1987 and Sinana on-station in 1990 exhibited a significant fertiliser by weed control synergism (Table 7). In both trials, +F responded more to weeding than did -F, although all responses were positive and significant. At Holetta, +W responded more positively to fertiliser than did -W.

TABLE 7. Effects of interaction of fertiliser application by weed control on bread wheat grain yield (kg ha^-1)

	Holetta 1987		Sinana OS90^a	
Weed control	-	+	-	+
Fertiliser:				
-	1437	1807	1747	2358
+	2624	3468	1606	2588
LSD (P=0.05)	256		251	

^a On-station 1990

At Holetta, weeding markedly improved fertiliser efficiency; weeding resulted in a conversion ratio of 19.4 kg grain per kg nutrient vs. 13.8 without weeding.

At Sinana in 1990, GY tended to decrease with fertiliser applied in the absence of weeding (-8%), but increased significantly when both factors were present (+48%). This suggests that weeds proliferated under the influence of fertiliser, and exerted a greater competitive effect on the unweeded wheat crop.

Variety by fertiliser. In the Sinana 1988 "Belg" trial, variety by fertiliser (P=0.069) interaction (Table 8) indicated that the semi-dwarf variety Dashen was more responsive to fertiliser than the unimproved farmers' variety Wollandi. In the absence of fertiliser, there was no difference between the 2 varieties, whereas with fertiliser, the GY of Dashen was greater than Wollandi. Wollandi exhibited no GY increment with added fertiliser.

TABLE 8. Effects of interaction of bread wheat variety by fertiliser application and insecticidal seed dressing on grain yield (kg ha^-1) at Sinana in 1988

	Belg season		Meher season	
	-F^a	+F	-I^b	+I
Variety:				
^c	1388	1611	1098	1276
+	1598	2224	1844	2462
LSD (P=0.1)	258		267	

^a Fertiliser (see Table 2)
^b Insecticide (see Table 2)
^c Varieties listed in Table 2

Variety by insecticide. In the Sinana 1988 "Meher" trial, variety by insecticide interaction was marginally significant (P=0.057). The GY of Dashen increased by 618 kg ha^-1 with insecticide (Table 8) while Wollandi exhibited a non-significant increase of 178 kg ha^-1. With or without aldrin, the GY of Dashen was greater than Wollandi. However, as for the other factors, the semi-dwarf exhibited a greater responsiveness to CM inputs.

Insecticide by weed control. In the Sinana 1990 on-station trials, weed control interacted significantly with insecticide

(Table 9). The GY of the unweeded treatments responded markedly to the aldrin seed treatment (+52%), while the weeded treatments responded to a lesser extent (+15%). Similarly, the GY of the -I treatments responded more (+73%) to weeding than did the +I treatments (+31%). Presumably, improved weed control facilitated the recovery of plants damaged by shoot fly attack, and control of shoot fly enabled wheat plants to compete more effectively with weeds.

TABLE 9. Effects of interaction of insecticidal seed dressing by fertiliser application and weed control on bread wheat grain yield (kg ha^- 1) in the on-station trialsa at Sinana in 1990

	Weed control		Fertiliser	
	-	+	-	+
Insecticide:				
-	1328	2303	1712	1919
+	2025	2643	2393	2275
LSD (P=0.05)	251		210b	

^a Mean of 2 trials (i.e., one in each season)
^b LSD at P=0.10 level

Insecticide by fertiliser. Also in the Sinana 1990 on-station trials, fertiliser response interacted significantly with insecticide (Table 9). The aldrin insecticide increased GY more in the absence of fertiliser (+40%) than when fertiliser was applied (+19%), suggesting that vigorous, well-fertilised wheat crops are damaged to a lesser extent by shoot fly or are better positioned to recover subsequent to the attack. Although the main effect of fertiliser on GY was non-significant in this particular trial, the fertiliser response in the absence of insecticide was almost significant at the P=0.1 level (Table 9) suggesting the effect of a yield compensation mechanism.

CONCLUSION

The main effects of varietal differences and the response to fertiliser and weed control exerted the greatest impact on wheat GY in all 13 trials. However, the two way interactions, particularly those involving variety, generally exhibited synergism between CM inputs, and emphasised the greater responsiveness of modern wheat varieties to improved management and higher levels of CM inputs. Overall, the results demonstrated the beneficial impact of combining improved production practices in one cultural package: the differences in GY between the farmers' practices and the recommended production package in each trial ranged from 801 to 4302 kg ha^-1.

The results of this study further emphasised the importance of on-farm agricultural research in Ethiopia since research station circumstances are often not representative of farmers' conditions, particularly in terms of differential response to fertiliser, weed control, and insecticide. Overall, agricultural researchers must be cautious in attempting to extrapolate results from on-station research to farmers' fields.

Furthermore, this study indicated that small-holders' wheat yields could be increased by over 70% in Sinana district with the introduction of seed of new varieties and the application of N and P fertiliser; the use of a seed treatment to control barley shoot fly was not justified by the on-farm response.

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