BIOLOGY AND CONTROL OF

Bromus pectinatus THUNB.

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Douglas Howard Wilcox

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"..... simple biological studies of individual species which might be suspected of increasing in importance are justified and provide ideal academic exercise for university students. Such studies on the life cycles and reproductive patterns may reveal ways in which a minor weed species can be prevented from becoming a major one."

Parker, 1977

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ABSTRACT

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Investigations into the biology and control of the annual grassy weed *Bromus pectinatus* Thunb. were conducted at the National Plant Breeding Station, Njoro, Kenya, from 1982 to 1984.

B. pectinatus is described and, in the tradition of other *Bromus sp.* of similar morphology, the common name Kenya Chess is proposed for *B. pectinatus*.

Pot growth of *B. pectinatus* was influenced by soil type and microclimate, but not by seed origin. *B. pectinatus* was germinated and grown in ammended and untreated soils ranging in pH from 3.05 to 8.13. Soils with a pH near 3 could not support growth or germination of *B. pectinatus*. *B. pectinatus* grew best on a soil of pH 6.55 and when soil pH influenced germination the optimum soil pH was 6.0. Out-of-doors grown *B. pectinatus* matured earlier and had fewer culms than plants grown in the shadehouse or glasshouse.

Exposure to light during germination, inhibited the germination of *B. pectinatus* seeds. Germination of *B. pectinatus* seed was most rapid at a 17 C temperature. Prechilling or preheating seeds did not promote germination of dormant *B. pectinatus* seeds. Germination of dormant *B. pectinatus* seeds was enhanced by seed hull removal or pricking the lemma or removing the rachilla segment.

Germination of *B. pectinatus* seed in the soil was unaffected by depth of burial, whereas, emergence was reduced to 35, 19, 11, 4 and 0% from depths of 0, 1, 2, 4 and 8 cm, respectively.

There was a relationship between field emergence of *B. pectinatus* and the precipitation pattern. After-harvest germination of *B. pectinatus* seed indicated that there was an innate dormancy in hulled seed which persisted for 8 months. The innate dormancy was mainly induced by the seed hull, but was also induced within the caryopsis itself.

Field measurements were used to develop an equation which related yield loss in wheat with *B. pectinatus* infestation. Delayed sowing of wheat and barley into a *B. pectinatus* infested site resulted in yield reductions that were correlated with length of delay.

Replacement series studies were conducted using varying proportions of wheat : *B. pectinatus* and rapeseed : *B. pectinatus*. Varying the proportions resulted in growth changes in the plants. *B. pectinatus* maturation was delayed when grown in a mixture. Rapeseed was unaffected by *B. pectinatus* interference.

A spatial interference study determined that *B. pectinatus* interfers with wheat mainly above ground.

The herbicides isoproturon, pendimethalin and oxadiazon were found to be ineffective against *B. pectinatus*. The herbicides triallate, chlorsulfuron, metribuzin, trifluralin and EPTC achieved limited control of *B. pectinatus*. Superior control of *B. pectinatus* was achieved using fluazifop-butyl at 0.25 kg/ha and fenthiaprop-ethyl at 0.12 kg/ha, in rapeseed.

FOREWORD

This thesis has been written in manuscript style. Chapters 1 to 6 will be submitted for publication in the East African Journal of Agriculture and Forestry.

INTRODUCTION

Bromus pectinatus Thunb. has recently been indentified as a serious weed problem of wheat and barley grown in the highlands of Kenya. A native plant of East Africa, *B. pectinatus* exists in nature as an annual ruderal, and was not known to be especially troublesome in crops. However, with successful control of wild oats (*Avena fatua*) and ryegrass (*Lolium sp.*) in cereals, a niche was opened which *B. pectinatus* was well suited to fill. *B. pectinatus* quickly spread from the headlands into this cereal field niche. The main reason for its spread was that *B. pectinatus* is extremely difficult to control with herbicides in cereals.

B. pectinatus seed germination is strongly influenced by dormancy and environment. Although a high proportion of the seeds germinate with the long rains, a significant proportion can continue to germinate throughout the cropping season. *B. pectinatus* competes early in the crop season and reduces yield, but is generally ripe and desiccated at harvest time and, therefore, does not interfere with harvest. Under good conditions *B. pectinatus* can produce 6,000 seeds per plant whereas one spikelet per plant will be produced when plants are so severely stunted by stress that they are only 10 cm high.

At present, *B. pectinatus* is a problem weed which cannot be consistantly controlled with existing herbicides in wheat or barley and is therefore a threat to continuous cereal production in Kenya. There is growing concern over the serious extent of infestation on some farms, and over the ever broadening distribution of the weed.

Research was initiated at the National Plant Breeding Station, Njoro, Kenya in 1982. The three objectives of this research were:

1.) to determine the distribution and importance of *B. pectinatus* as a weed; 2.) to conduct herbicide trials to develop immediately applicable control recommendations for farmers; and, 3.) to study the biology of *B. pectinatus* to enable development of a long-term integrated approach to *B. pectinatus* control in Kenya.

LITERATURE REVIEW

Bromus pectinatus Thunb., Biology and Ecology

Only four, of the approximately 50 *Bromus* species that have been identified, are found in Kenya (Clayton, 1971). Of these four, only *Bromus diandrus* Roth. and *Bromus pectinatus* Thunb. are considered common weeds (Ivens, 1967). Of these two *B. pectinatus* is the most severe weed in cereal crops.

The most recent compilation of the morphology and distribution of the *Bromus* species found in Kenya, and specifically of *B. pectinatus*, is found in Clayton (1971). Descriptions of *B. adoensis* Steud. (*B. pectinatus*) can be found in Napper (1966) and Bogdan (1958). Clayton (1971) suggested that *B. pectinatus* is probably not distinct from the Australian species *B. arenarius* Labill. A description of *B. arenarius* can be found in Hitchcock and Chase (1950).

Distribution

B. pectinatus has been identified in locations all along the eastern side of the continent of Africa. It has been collected in South Africa, Tanzania, Uganda, Kenya, Sudan Republic, Ethiopia, Egypt, the Sinai and Turkey (Clayton, 1971; Pollard *et al.*, 1984). *B. arenarius* has been found in the United States of America and Australia (Hitchcock and Chase, 1950).

B. pectinatus occurs as a troublesome weed only in East Africa and

Turkey (Pollard *et al.*, 1984). Clayton (1971) described *B. pectinatus* as "a ruderal of weedy places and old farmland in the uplands". In Kenya *B. pectinatus* is often the major weed in wheat and barley fields. This distribution may, in part, be due to the domination of agriculture in the highlands by wheat and barley production. These uplands are the natural habitat of *B. pectinatus*.

Clayton (1971) suggested that the habitat of *B. pectinatus* in East Africa is altitudes between 2,200 and 3,000 m. Tieszen *et al.* (1979) found that the distribution of C_4 and C_3 grasses followed an altitude and moisture gradient in Kenya. *B. pectinatus* is a C_3 grass (Imbamba, 1979) and Tieszen *et al.* (1979) determined that in the open grasslands of Kenya there were no C_3 species at altitudes less than 2,000 m. They also observed that *Bromus* species were found at the warmer end of the distribution of C_3 plants and that species of the tribe *Festuceae*, to which *Bromus* belongs, require an environment with a relatively high available soil moisture.

Biology and Ecology of Selected *Bromus* Species

Management techniques for controlling annual weeds (such as *B. pectinatus*) are considered successful if they reduce seed numbers in the soil (seedbank), reduce weed emergence, or reduce weed interference (Aldrich, 1984). Management of *B. pectinatus* is difficult because *B. pectinatus* has many characteristics of the ideal weed as outlined by Baker (1974).

Seedbank

The number of weed seeds returned to the soil seedbank with a new crop can be significant, especially with uncleaned seed. In the Oklahoma wheat growing regions, which are heavily infested with *B. secalinus*, dockage levels in harvested wheat averaging 10 to 15% and as high as 35% have been observed (Greer *et al.*, 1980). Finnerty and Klingman (1962) reported one Russian researcher who observed that on one collective farm, winter rye grown from seed containing 0.5% *B. secalinus* had 16.3% *B. secalinus* in the harvested grain.

Germination

Germination will not proceed unless the major factors of water, oxygen, temperature and light are satisfactory and dormancy is absent (Bidwell, 1979). Steinbauer and Grigsby (1957a, 1957b) observed that *B. secalinus* seed placed under germination conditions one day after harvest did not germinate at temperatures above 15 C unless the seed was prechilled for one week at 5 C, or was kept in dry storage for one month. The seed would then germinate at all temperatures up to 30 C. *B. secalinus* may germinate at quite cold temperatures. Beal (1897) observed kernels of *B. secalinus* germinating in contact with ice, the roots having penetrated into a block of ice for most of their length.

In *B. mollis* it has been observed that the best germination occurs under alternating temperatures (Young *et al.*, 1973).

Light is important in the germination of some weed species (Andersen, 1968). Light intensity, duration and wavelengths are important factors in determining seed response to light (Andersen, 1968). Steinbauer and Grigsby (1957a) observed that light from a

fluorescent lamp had no effect on germination of *B. secalinus*. However, Hulbert (1955) observed that germination of 5.5 month old *B. tectorum* and freshly harvested *B. brizaeformis* seed was inhibited when exposed to greenhouse light. He also observed that one year old *B. brizaeformis* seed was not inhibited by greenhouse light. Pollard (1982) observed that sunlight inhibited germination in *B. sterilis*, and the nature of this inhibition has recently been studied by Bartley and Frankland (1984) and Hilton (1984a, 1984b).

Hilton (1984a) observed that, in addition to light, inhibition of *B. sterilis* can be modified by temperature and moisture. She suggested that the ecological significance of this affect is that seed, freshly shed in the fall, will be inhibited by moisture stress and light, while low temperatures and moisture stress would prevent germination through the winter and into spring.

Scarification often increases germination by increasing the permeability of the seed to water or oxygen (Anderson, 1968). Harper (1977) commented that seeds that require scarification tend to break dormancy at different times rather than as a sudden flush. One method of scarification is simply to prick the seed coat with a pin. Pollard (1982) observed that pricking the seed of *B. sterilis*, one day after inhibition stimulated its germination.

Seed density at germination can be important in germination. Linhart (1976) reported that increasing *B. inermis* seed density from 5 to 200 seeds per unit area caused a decrease in the percentage germination. He also observed that *B. tectorum* showed no difference in germination response when seed density was increased from 50 to 200 seeds per unit area (does not state dimensions).

Emergence

Provided the major germination factors are adequate, depth of burial will not affect germination (Aldrich, 1984). However, depth of burial will affect emergence. McNeil and Peeper (1978) studied the emergence of *B. secalinus* buried at various depths in the soil. They observed 35% germination of surface placed seed, seed placed 1" deep had 92% emergence, at 2" deep 74% emerged, at 4" deep only 1% emerged, and from the 6" and 8" depths no seedlings emerged. In field studies Runyan and Peeper (1979b) observed that moldboard plowing 8" or 12" deep then discing 3" or 4-7", respectively, reduced the problem of *B. secalinus*.

Dormancy

Seed dormancy is a state in which germination will not occur even though the environment can support germination (Aldrich, 1984). The purpose of seed dormancy is to protect the seed from germinating into unfavorable conditions. There are three types of dormancy. Dormancy can be innate, induced or enforced. These three types of dormancy are briefly described, respectively, in the following quote from Harper (1977): "Some seeds are born dormant, some aquire dormancy, and some have dormancy thrust upon them.".

Laude (1956) studied greenhouse planted *B. mollis*, *B. rigidus*, *B. rubens*, and *B. tectorum*. He observed dormancy in all these *Bromus* species. This dormancy decreased with time, and by 5 months after harvest there was no dormancy in seed from any of the *Bromus* species. He also observed that the rate of seedling emergence increased with time, as dormancy was broken.

Harris (1961) observed that most freshly harvested seeds of *B.*

mollis germinated early although some seeds did not germinate until after several months. McGowan (1970) studied *B. mollis* in Australia and observed a considerable autumn dormancy. Despite the dormancy, he measured a very low level of viable seed carryover from one year to the next. Chancellor (1980) stated that the seeds of *B. mollis* are short lived and have minimal dormancy. Jain (1982) suggested that the innate dormancy of Californian *B. mollis* is very important in timing germination to ensure the availability of fall moisture. He also determined that the variation in dormancy among different populations of *B. mollis*, from California, was low.

Steinbauer and Grigsby (1957a) observed that 90% of the *B. secalinus* seeds they had fall planted had emerged within one to two months of planting. They suggested that the innate dormancy in *B. secalinus* probably does not exceed four or five weeks and that most of the seeds of this species probably germinate in the same season they are formed. They also determined that innate dormancy in *B. secalinus* could be overcome by a low constant temperature such as 15 C, or a prechilling treatment of five to seven days duration.

The duration of innate dormancy will determine control measures. Finnerty and Klingman (1962) suggested that practical control of weedy bromegrasses (including *B. secalinus*) can be obtained by prevention of seed production for a period of two years.

Steinbauer and Grigsby (1957a) observed that *B. secalinus* stored in dry sealed containers (an enforced dormancy) had 91% germination after eight years of storage.

Interference

Interference is the total adverse effect that plants growing in a common ecosystem exert on each other (Anonymous, 1985). This interference can occur as a result of competition, changes in environment, or allelopathy (Harper, 1977).

Allelopathy. *Bromus* species can be sensitive to toxins from other plants. Muller (1966) observed that seedling growth of *B. mollis*, *B. rigidus* and *B. rubens* was inhibited when germinated in the presence of *Salvia leucophylla* plant material. Rice (1971) observed that *B. japonicus* leachates would inhibit nodulation of heavily inoculated Korean lespedeza (*Lespedez stipulacea*).

Competition. Competition is the reduction in supply of resources to one organism as a result of active aquisition by another (Anonymous, 1985). Competition is the most common interference mechanism between plants. The competitive plant must be more successful in resource capture and the competitiveness is determined by such factors as the distance from neighbours, plant size, time of competition (Harper, 1977), and plant vigour and hardiness (Zimdahl, 1980). Competition can occur between plants for the resources of nutrients, light, water, carbon dioxide and oxygen (Aldrich, 1984).

Competitive weeds will be good colonizers. Allard (1965) stated that the majority of plants that have been successful as colonizers are predominately self-pollinated species. Baker (1974) in his ideal weed characteristics lists self-compatability as an advantageous characteristic.

Hulbert (1955) suggested that self pollination is the rule for most annual bromegrasses, including *B. mollis*. Allard (1965) even suggested

that *B. mollis* is capable of "adjusting" its level of outcrossing to give it flexibility to optimize occupations of diverse habitats.

Increasing seeding rate can increase the competition by a crop against a weed. Runyan and Peeper (1979b) observed that wheat seeding rates at or above 60 lb/A decreased the *B. secalinus* weed problem compared to a 30 lb/A seeding rate.

The effect of a crop on a weed will vary with the cultivar used. Burnside *et al.* (1983) determined that some winter wheat cultivars were non-competitive against *B. secalinus* because of their low tillering ability and low tiller weight/m^2. Runyan and Peeper (1979b) compared normal height and semi-dwarf wheat cultivars and found no difference in their competitive ability with *B. secalinus*.

Planting date can also be important in determining the extent of competition. Runyan and Peeper (1979b) observed, that in wheat sown into a *B. secalinus* infested sites at three week intervals from September to December, that the best yields were obtained from October sown plots. They also observed that delaying planting did not eliminate the *B. secalinus* problem.

In Oklahoma, Greer *et al.* (1980) found that the average yield losses due to *B. secalinus* were 5-6 bu/A in wheat.

Changes in Environment. Cultural practices influence the occurance of *Bromus* species. Smith (1970) studied *B. mollis* populations in a grassy glade. He observed that straw removal was the most effective method for reducing the numbers of germinating *B. mollis* seedlings, followed by burning or soil disturbance, and clipping.

Peel and Hopkins (1980) stated that *B. mollis* thrives in hay fields where it has had a chance to shed seeds before being cut. They also

suggested that a reason for its thriving in pastures was that *B. mollis* has a large and prominant seedhead which is unpalatable to grazing livestock and in hay.

Insect predation may limit the distribution of a plant (Harper, 1977). Pettersson (1971) observed that fast growing annual grasses, such as *B. secalinus*, are more attractive to aphids (*Schizaphis* species) than slow growing biennial grasses.

Seed production can be influenced by environment. Finnerty and Klingman (1962) demonstrated that *B. secalinus* panicle production was influenced strongly by temperature and photoperiod. They also determined that moisture, soil fertility and light were important. The importance of temperature and photoperiod is perhaps best demonstrated by their observation that *B. secalinus* did not head in the same year if planted during mid-March or later. Hulbert (1955) observed that for normal flowering to occur in *B. mollis* and *B. secalinus* that they must be subjected to cold temperatures. For *B. sterilis* he observed that this cold treatment was not necessary.

Mijatovic (1973) and Winans and McKell (1963) observed that in rangelands to which nitrogenous fertilizer was added in the spring, that growth and vigour of *B. mollis* was encouraged more than other grasses. Major (1962) observed a similar effect with *B. secalinus* in pot trials. He observed that the yield of *B. secalinus* was closely correlated with increasing nitrogen applications up to 400 ppm.

Sulfur has also been shown to be an important nutrient for the growth of *B. mollis*. Walker and Williams (1963) showed that the addition of nitrogenous fertilizers to annual grasslands increased the growth of *B. mollis* and *Erodium botrys* concurrently, but when sulfur was

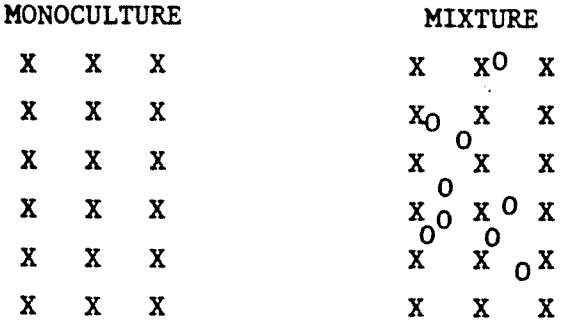
applied as well, dominance shifted to *B. mollis*. McCown and Williams (1968) demonstrated that this shift was not due to a higher sulfur requirement for *B. mollis* but instead was due to the elimination of a sulfur deficiency which permitted *B. mollis* to grow better and become more competitive for light.

Soil pH is often a factor determining weed distribution (Aldrich, 1984). Soil pH may influence plant growth through the effects on nutrient availability or toxicity (Follet *et al.* 1981). Gupta (1969) observed that *B. inermis*, on soils with a pH of 5.0, showed a marked increase in growth and vigour in response to applications of lime, but did not respond to applications of molybdenum. Mott (1962) found that treatment of acid swards (pH 4.15-4.3) for 10 or more years with alkaline NPK fertilizer was more favorable to *B. mollis* establishment than was treatment with acid NPK fertilizer.

Interference Experiments. There are two basic experimental schemes used to analyse interference between plants. These two schemes are the additive scheme and the replacement scheme (Harper, 1977).

Additive Scheme. In the additive scheme the weed population is "added" to the crop population and the yield of the "weedy" crop is compared to the yield in a weed free crop (Spitters and Van den Bergh, 1982) (Figure 1A). The additive scheme is the most useful in that it is the most relevant to field situations, answering to what extent crop yield is reduced by presence of a weed (Spitters and Van den Bergh, 1982). The disadvantage of the additive design is that the proportional composition and density of the mixture often both change over time which leads to complete confounding of effects (Harper, 1977).

Replacement Scheme. Replacement series schemes were first



A.) Additive scheme

CROP MONOCULTURE	MIXTURE	WEED MONOCULTURE
X X X	X O X	O O O
X X X	O X O	O O O
X X X	X O X	O O O
X X X	O X O	O O O
X X X	X O X	O O O
X X X	O X O	O O O

B.) Replacement scheme

Figure 1. A comparison of additive and replacement schemes with crop plants (X) and weed plants (O). (Adapted from Spitters & Van den Bergh, 1982)

introduced by Wit (1960) and his competition model is the most adequate for quantifying replacement experiment competition effects (Spitters and Van den Bergh, 1982). In the replacement (substitution) scheme all plots have the same stand densities, but a range of mixtures is obtained by starting with a crop in monoculture and gradually replacing a portion of the crop plants with weed plants until a weed monoculture is obtained in the final plot (Spitters and Van den Bergh, 1982) (Figure 1B).

The disadvantage of replacement series schemes is that, they are artificial in that, they do not represent practical weed problems (Spitters and Van den Bergh, 1982). In replacement schemes density is constant, whereas, most plant populations change in density as they change in proportion (Harper, 1977). Also, as Inouye and Schaffer (1981) pointed out, when replacement series experiments are conducted at different densities, different competitive outcomes may arise. Spitters and Van den Bergh (1982) suggested that a design which utilizes dynamic simulation of the competitive effects over time may overcome these arguments.

Normally a measure of the relative crowding coefficient (RCC) is derived from the results of a replacement series experiment (Wit, 1960). However, a RCC is inappropriate if the combined yields of a mixture cannot be predicted from the pure stands (Harper, 1977). Under such circumstances, the Relative Yield and Relative Yield Totals are used to give a measure of the degree of the degree of niche differentiation (Spitters, 1983).

A replacement series model assumes that interference ability is independent of planting pattern. In small cereals, if planting is not too variable this is a good assumption (Spitters and Van den Burgh,

1982). However, arrangement still may be important. Harper (1961) studied interference between *B. rigidus* and *B. madritensis* by holding density and mixture proportion constant while varying plant arrangement. He observed that plant arrangement had a market effect on ultimate yield of the two species.

Although replacement schemes are "particularly elegant for the study of plant interactions involving two species" (Harper, 1977), it is important to remember that inferences, about competition between species, cannot be drawn from any single replacement series experiment (Inouye and Schaffer, 1981).

Chemical Control of *Bromus pectinatus* Thunb.

In Kenya, there is no herbicide recommended for controlling *B. pectinatus* in wheat (Anonymous, 1983). For barley, triallate {S-(2,3,3,-trichloro-2-propenyl)bis(1-methylethyl)carbamothioate} at 2.4 kg/ha, is recommended for control of *Bromus* species (Owino *et al.*, 1983). This activity of triallate against *Bromus* species in barley is rated as acceptable, not as excellent.

The urea herbicides chlorotoluron {N^1-(3-chloro-4-methylphenyl)-N, N-dimethylurea}, methabenzthiazuron {N-(2-benzothiazolyl-N, N^1-dimethylurea}, and metoxuron {N^1-(3-chloro-4-methoxyphenyl)-N, N-dimethylurea} have been tested against *B. pectinatus*. Owino and Little (1979) determined in field trials that chlortoluron at 1 and 2 kg/ha, methabenzthiazuron at 1.4 to 1.75 kg/ha and metoxuron at 3.2 to 4.8 kg/ha, sprayed during barley tillering had no effect on *B. adoensis* (*B. pectinatus*) control. Whereas, when they used preemergent applications of chlortoluron (3 and 4 kg/ha) and metoxuron (4 kg/ha) they observed about 50% and 28% control, respectively, of *B. pectinatus*.

Several auxin inhibiting herbicides have been field tested against *B. pectinatus* and were found ineffective. Benzoylprop-ethyl {ethyl ester of N-benzoyl-N-(3,4-dichlorophenyl)-DL-alanine} at 0.6 kg/ha and flamprop-isopropyl {isopropyl ester of N-benzoyl-N-(3-chloro-4-fluorophenyl)-DL-alanine} at 1.25 kg/ha were sprayed into a barley field at the first node stage, and diclofop-methyl {methyl ester of (±)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid} at rates 0.72 to 1.08 kg/ha was sprayed into a barley field at the end of tillering stage. All were found to have no efficacy against *B. adoensis* (*B.*

pectinatus) (Owino and Little, 1979).

Thiolcarbamate herbicides have been successful in partially controlling *B. pectinatus*. Pollard *et al.* (1984) observed in glasshouse pot experiments that EPTC {S-ethyl dipropyl carbamothioate} at 0.75 kg/ha gave complete control of *B. pectinatus*. Lowering the EPTC rate to 0.5 kg/ha and 0.25 kg/ha allowed only 98% and 91% control, respectively. Owino and Little (1979) achieved 34% and 48% control of *B. adoensis* (*B. pectinatus*) by using 1.6 kg/ha and 2.0 kg/ha, respectively, of triallate emulsifiable concentrate preplant incorporated (ppi) into their plots. They had even greater success with triallate granules. Control of about 80% was achieved when they used triallate granules at 2.5 kg/ha and 3.5 kg/ha ppi. Control dropped to 70% when the triallate granules were used preemergent incorporated at 3.5 kg/ha.

Control of *B. pectinatus* has been successful with the as-triazinone herbicides isomethiozin {6-(1,1-dimethylethyl)-4-[(2-methylpropylidene) amino]-3-(methylthio)-1,2,4-triazin-5-(4H)-one} and metribuzin {4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one}. In field trials Owino and Little (1979) observed that 55% control of *B. adoensis* (*B. pectinatus*) was achieved when isomethiozin at 1.25 kg/ha was applied to a field of barley at the mid-tillering stage. They also found that 0.6 kg/ha of metribuzin applied to a barley field at mid-tillering stage gave 26% control of *B. adoensis* (*B. pectinatus*). In glass house trials, metribuzin applied preemergence to pots containing *B. pectinatus* at rates of 0.075, 0.15 and 0.30 kg/ha caused reductions in *B. pectinatus* fresh weights, 29 days later, to 39, 10 and 1%, respectively (Richardson and Pollard, 1984).

Richardson *et al.* (1979) conducted a series of trials on glasshouse

pot grown *B. pectinatus* plants. Five of the six preemergent herbicides they tried were effective against *B. pectinatus*. They determined that 4.0 kg/ha pendimethalin { N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine } , 4.0 kg/ha butralin { 4-(1,1-dimethylethyl)-N-(1-methylpropyl)-2,6-dinitrobenzenamine } and 1.6 kg/ha of R40244 (fluorochloridone) { 1-(m-trifluoro-methylphenyl)-3-chloro-4-chloromethyl-2-pyrrolidone } reduced the vigor or numbers of *B. pectinatus* by 70% or more. They also determined that FMC 39821 {C-5-(2-chloro-benzyloxy)-r-2-ethyl-C-4-methyl-1,3-dioxane} was effective against *B. pectinatus* at rates as low as 0.1 kg/ha. They suggested that AC 206784 { 2-chloro-N-(2,3-dimethylphenyl)-N-(1-methylethyl)acetamide} might provide selective control of *B. pectinatus*, in wheat, at a high rate of 4.0 kg/ha.

In glasshouse pot trials, Richardson *et al.* (1979) determined that acifluorfen { 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid } at rates up to 1.6 kg/ha had no significant effect on *B. pectinatus*. In field trials, Owino and Little (1979) determined that cyanazine { 2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile} at 0.5 kg/ha and pendimethalin, to 2 kg/ha, applied to barley near the end of tillering, and difenzoquat {1,2-dimethyl-3,5-diphenyl-1H-pyrazolium} at 1.0 kg/ha, applied to barley at the first node stage, all had no significant effect on *B. adoensis* (*B. pectinatus*).

Herbicides

Chlorsulfuron. Chlorsulfuron {2-chloro-N-[[(4-methoxy-6-methyl-1, 3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide} is a sulfonylurea herbicide (Ray, 1984). Chlorsulfuron is primarily recommended for weed control in small grain cereals (Levitt *et al.*, 1981). Its main mode of action is to block the biosynthesis of the amino acids valine and isoleucine in plants (Ray, 1984). The selective toxicity of chlorsulfuron is due to the ability of some plants to metabolize chlorsulfuron to inactive products (Sweetser *et al.*, 1982). It is a herbicide which is active at extremely low concentrations (Fedtke, 1982). Preemergent applications of chlorsulfuron, at 8 g/ha, have been adequate to partially control some *Bromus* species (Levitt *et al.*, 1981).

EPTC. EPTC is a member of the thiolcarbamate group of herbicides (Fedtke, 1982). The primary mode of action of thiolcarbamate herbicides is to inhibit complete germination of gramineous species by entering the leaves of young shoots still enclosed in the coleoptile (Anderson, 1983). Inhibition likely occurs by disruption of cellular division, elongation or expansion. Generally, thiolcarbamates display little phytotoxicity to dicotolydenous species (Fedtke, 1982).

For optimum weed control EPTC must be mechanically incorporated into the soil, to a depth of 5 to 6 cm, immediately after application, to minimize volatilization (WSSA, 1983).

In pot experiments Pollard *et al.* (1984) observed control of *B. commutatus*. *B. hordeaceus* (*B. racemosus*), *B. pectinatus* and *B. sterilis* by EPTC at rates of 0.25, 0.5, and 0.75 kg/ha.

Fenthiaprop-ethyl. Fenthiaprop-ethyl {(RS)-2-[4-(6-chloro-1,3-benzothiazol 2-yloxy)phenoxy]propionic acid} was most active as a

post-emergent treatment (Olson and Ehlhardt, 1983) and provided effective control of annual and perennial grasses over a wide range of growth stages (Reuss *et al.*, 1984). Fenthiaprop-ethyl displayed rainfastness (Reuss *et al.*, 1984) and in field and lab trials has demonstrated rapid degradation (Bieringer and Bauer, 1984).

Fenthiaprop-ethyl has demonstrated excellent selectivity for grass and volunteer cereals in a number of broadleaved crops in onions (Richardson *et al*, 1983). In field trials in France, application of 180 g/ha gave excellent control of 3-leaf and 1-tiller stage grasses without damage to the rape crop (Erny *et al.*, 1983).

Fluazifop-butyl. Fluazifop-butyl {(±)-butyl 2-[4-[(5-(trifluoromethyl)-2-pyridinyl)oxy]phenoxy]propanoate} is a member of the diphenoxy-carboxylic family of herbicides (Anderson, 1983). Fluazifop-butyl is a highly selective post-emergence grass killer for control of both annual and perennial grasses in all broadleaf crops (WSSA, 1983).

Recommended dosages for annual grass control range from 0.28 kg/ha to 0.56 kg/ha (Anderson, 1983). Fluazifop-butyl is rapidly absorbed by plant foilage and translocated in both the xylem and phloem (WSSA, 1983). However, the phytotoxic action of fluazifop-butyl is relatively slow (Anderson, 1983). It is recommended that a nonionic surfactant or oil concentrate be added to fluazifop-butyl to improve efficacy.

Fluazifop-butyl is rapidly degraded in moist soils (WSSA, 1983) but at rates of 0.56 to 1.13 kg/ha the herbicide may cause injury to grass crops sown up to 3 months after application (Anderson, 1983).

Glyphosate. Glyphosate {N-phosphonomethyl glycine} is an

unclassified herbicide (Anderson, 1983). The main mode of action of glyphosate is to inhibit biosynthesis of aromatic amino acids in plants (Fedtke, 1982).

Glyphosate is a very broad spectrum, relatively nonselective and non residual, post emergent herbicide (WSSA, 1983). Absorption is through the foliage and translocation is throughout the whole plant. A complete review of the herbicide glyphosate can be found in Grossbard and Atkinson (1985).

Control of *Bromus* species has been achieved with glyphosate. *B. japonicus* was controlled with 2.25 kg/ha of glyphosate (Runyan and Peeper, 1979b). Martin and Moomaw (1974) and Petersen *et al.* (1983) also controlled *B. japonicus* with glyphosate. *B. mollis* has been controlled by glyphosate at 0.4 kg/ha (Hughes, 1976). *B. secalinus* and *B. tectorum* were controlled with 2.25 kg/ha of glyphosate by Runyan and Peeper (1979b). Glyphosate has successfully controlled *B. inermis* by rates of 1.12 kg/ha (Waller and Schmidt, 1983), 1.7 kg/ha (Putnum *et al*, 1974) and 2.6 kg/ha (Mueller-Warrant and Koch, 1980).

Isoproturon. Isoproturon {N,N-dimethyl-N-[4-(1-methylethyl) phenyl]urea} is a phenylurea herbicide (Kirkwood *et al*, 1984). The primary mechanism of action of isoproturon is inhibition of the Hill reaction of photosynthesis (Kirkwood *et al.*, 1984).

Isoproturon is used mainly to control annual grasses and broadleaved weeds in wheat, barley and rye, at rates of 1.0 to 1.5 kg/ha (Martin and Worthing, 1977). Within a plant isoproturon movement is almost entirely within the xylem (Kirkwood *et al.*, 1984). Selectivity in isoproturon may be due to differential binding of isoproturon molecules to chloroplast membranes.

Metribuzin. Metribuzin is a member of the as-triazinone herbicide family (Fedtke, 1982). The primary mechanism of the as-triazinone herbicides is to inhibit photosynthesis.

Metribuzin is effective against annual grasses and many broadleaf weeds (WSSA, 1983). The major route of metribuzin uptake by plants is through the root system. Preemergent or early post-emergent applications of metribuzin give best results.

Metribuzin is translocated mainly through the xylem (WSSA, 1983) and the main factor in plant tolerance of metribuzin is its rapid detoxification in tolerant plants (Fedtke, 1982). There has been great differences observed in selectivity of metribuzin to winter wheat cultivars (Gigax, 1979; Greer *et al.*, 1980).

Greer *et al.* (1980) observed effective control of *B. secalinus*, *B. willdenowii*, *B. tectorum*, *B. japonicus*, and *B. commutatus* with metribuzin. Metribuzin at 0.42 kg/ha has been observed to give satisfactory control of *B. secalinus* (Carmean and Russ, 1982; Fischer and Peeper, 1981; Gigax, 1979). However, this rate of metribuzin may have to be increased to 0.56 kg/ha on heavy soils (Stanley and Cagle, 1979) or if applied in March instead of November (Carmean and Russ, 1982). Metribuzin was found to be more toxic to *B. secalinus* under grazed conditions (Runyan and Peeper, 1979a). Pot grown *B. sterilis* was susceptible to metribuzin at rates from 0.075 kg/ha to 0.30 kg/ha (Richardson and Pollard, 1984).

Oxadiazon. Oxadiazon {3-[2,4-dichloro-5-(1-methyl-ethyoxy) phenyl]-5-(1,1-dimethylethyl-1,3,4-oxadiazol-2-(3H)-one} is used in Kenya for weed control in rice. Oxadiazon is used to control some grasses and broadleaved weeds at rates of 0.84 to 4.48 kg/ha (WSSA,

1983).

Oxadiazon is strongly absorbed by soil and exhibits only minor volatilization (WSSA, 1983). The mechanism of action of oxadiazon is to affect, by contact action, the young shoots of plants as they grow through the treated zones in the soil.

Pendimethalin. Pendimethalin is a member of the dinitroanaline family of herbicides (Fedtke, 1982). Pendimethalin, applied preemergence at a 1.5 kg/ha rate, is recommended for use in wheat and triticale in Kenya for *Setaria* species control (Anonymous, 1983).

The primary mechanism of action of dinitroanaline herbicides is to interfere with the assembly or function of cell microtubule systems (Fedtke, 1982). The primary mechanism of action of pendimethalin is reportedly related to inhibition of cell division and elongation (WSSA, 1983).

There is only limited foliar absorption of pendimethalin by monocotyledonous plants (WSSA, 1983). Preplant, preemergence and early post emergence treatments are the suggested application times. Pendimethalin is strongly absorbed to soil and only limited amounts are taken up from the soil and translocated within the plant.

Triallate. Triallate is a member of the thiolcarbamate herbicide family (Fedtke, 1982). Thiolcarbamate herbicides are germination inhibitors, which primarily affect gramineous species. Triallate is absorbed by the coleoptile of some grass species where it then acts by inhibiting cell division and elongation (WSSA, 1983).

Triallate is generally used primarily for wild oat control (WSSA, 1983). In Kenya, triallate at 2.4 kg/ha was recommended for *Bromus*

species control in barley (Owino *et al.*, 1983). Preplant and postplant triallate applications are most effective when properly incorporated to minimize volatilization at high temperatures (WSSA, 1983).

Trifluralin. Trifluralin {2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamide} is a member of the dinitroanaline herbicide family (Fedtke, 1982). The primary mechanism of action of trifluralin is to affect the physiological growth processes involved in seed germination (WSSA, 1983). In general, dinitroanaline herbicides interfere with the function and assembly of plant microtubular systems (Fedtke, 1982).

Trifluralin at rates of 0.6 to 1.1 kg/ha is recommended for controlling annual grasses such as *B. tectorum* and *B. secalinus* (WSSA, 1983). There is almost no contact activity or translocation of trifluralin into crops. Trifluralin is a preemergence herbicide that must be incorporated to minimize volatilization and photodecomposition. However, deep incorporation did not improve the efficacy of trifluralin against *B. rigidus* or *B. tectorum* (Mundt and Lee, 1979).

CHAPTER 1

Bromus pectinatus Thunb. Morphology

ABSTRACT

A description of *Bromus pectinatus* Thunb., a grassy weed of Kenya, is presented. The description is used to determine *Bromus* species that might be closely allied to *B. pectinatus*. Kenyan Chess is suggested as a common name for *B. pectinatus*.

INTRODUCTION

McNeill (1976) states:

> in weed science there is a continuing need for clear, easily used and up-to-date manuals permitting recognition of weed species at all stages of their development.

In Kenya grassy weeds, such as *Bromus pectinatus* Thunb., can be difficult to identify. Clayton (1971), of the *Flora of Tropical East Africa* series, contains descriptions of the grassy weeds found in Kenya. However, to many weed researchers in Kenya, the descriptions given in this series are difficult to use. Difficulties arise because all grasses, not just weedy grasses, are listed and the botanical descriptions provided may neglect the terminology and characteristics to with which a weed researcher is used to working. It has also been observed by this author that some of the ranges of measurements of plant parts given for *B. pectinatus* by Clayton (1971) and for *B. adoensis* Steud. *(B. pectinatus)* by Napper (1966) and Bogdan (1958) are not the

same as what this author has measured. This report presents a description of *B. pectinatus* which the author believes is more suitable to weed researchers than is the description given in Clayton (1971).

An extensive search of the literature has revealed that there is little information on management of *B. pectinatus*. The reasons for the lack of information is that *B. pectinatus* has only recently become a weed of concern and where it is of concern is mainly in countries which have underdeveloped weed research programs. Hints as to which management techniques might suppress *B. pectinatus* weediness might be found by studying the literature available on closely allied *Bromus* species. Closely allied *Bromus* species, most likely, would be morphologically and karyotypically similar. This report determines those *Bromus* species which are most likely to be closely allied to *B. pectinatus*.

MATERIALS AND METHODS

The plants used in making the description, in this report, were identified using the description of *B. pectinatus* in Clayton (1971). Some specimens were also verified by Miss C. Kabuye at the East African Herbarium, Nairobi.

The description presented was developed from observations during numerous field trips throughout Kenya, studying herbarium specimens of *B. pectinatus* at the East African Herbarium, and observations and measurements on plants grown in field and greenhouse experiments. Many of the observations and measurements, recorded by the author, are not present in either the description of *B. pectinatus* by Clayton (1971) or

the descriptions of *B. adoensis* Steud. (*B. pectinatus*) by Bogdan (1958) or Napper (1966).

The description is written up according to the style suggested by Stearn (1973).

Mature plant height was measured as the distance from the soil surface to the apex of the highest spikelet when the panicle was extended. Leaf width was measured at the widest portion of the leaves. Leaf length was measured from the collar region to the leaf tip in an extended leaf. Panicle length was measured as the distance from the flag leaf collar to the apex of the highest spikelet when the panicle was extended. All other measurements were direct.

For this report a closely allied species is defined as one that has a morphological and karyotypic resemblance to *B. pectinatus*. There are approximately 50 identified species of *Bromus* (Clayton, 1971). Hitchcock and Chase (1950) divide the *Bromus* species into four morphological groupings. The description of *B. pectinatus* developed in this report is used to categorize *B. pectinatus* into one of these four morphological groups. Chromosome numbers given in Fedorov (1969) are used to decide which morphologically similar *Bromus* species are broadly karyotypically similar to *B. pectinatus*.

RESULTS AND DISCUSSION

Morphological Description of *Bromus pectinatus* Thunb.

Growth habit, tufted annual grass, 10-90(-125) cm high; *Roots*, fibrous; *Culms*, solitary, slender, erect, bent at base, very

occasionally rooting from a lower node, almost all culms will bear an inflorescence; *Leaf sheaths*, pubescent, keeled, tubular, sometimes splitting, basil sheaths often reddish tinged; *Ligule* (Figure 2-2), long, membranous, lacerate; *Collar*, narrow, distinct, divided; *Leaf blades*, 5-12(-16) mm wide, 5-30 cm long, V-shaped, keeled, lanceolate, accuminate tiped, rounded base, smooth margins, scabrid adaxial surface, smooth abaxial surface, leaf surfaces sometimes puberulent, mature leaves often twisted, auricles absent, first leaf clockwise twisted (Figure 2-1); *Inflorescence* (Figure 2-3), open, oblong, nodding, panicle, 5-25 cm long; *Spikelets* (Figure 2-6), 10-30 mm long, 4-9 flowered, laterally compressed, except for basal seed, readily disarticulates below glumes when mature; *Glumes* (Figure 2-7 and 8), lanceolate, keeled, laterally compressed, acuminate three-nerved lower glume 5-10 mm long, accute five-nerved upper glume 7-14 mm long; *Lemma* (Figure 2-5), narrowly ovate, seven nerved, accutely bidentate, two or more keels, scabrous; callus short and rounded; awn, simple, straight, arising 1-3 mm below hyaline tip, 7-17 mm long, lower awns often shorter than upper; *Palea* (Figure 2-4), reaches to awn base, translucent, keels pectinate-ciliate with hairs to 0.5 mm long; *Anthers*, yellow, 1 mm long, three stamens; *Grains*, dark brown to light grey-green, eliptical.

Similar Species

Using the criteria, that *B. pectinatus* is an annual, with straight awns less than 17 mm long, spikelets which are terete before anthesis and broad lemmas with short (< 1 mm) teeth, would place it within the *Bromium* grouping of Hitchcock and Chase (1950). The names of the *Bromus*

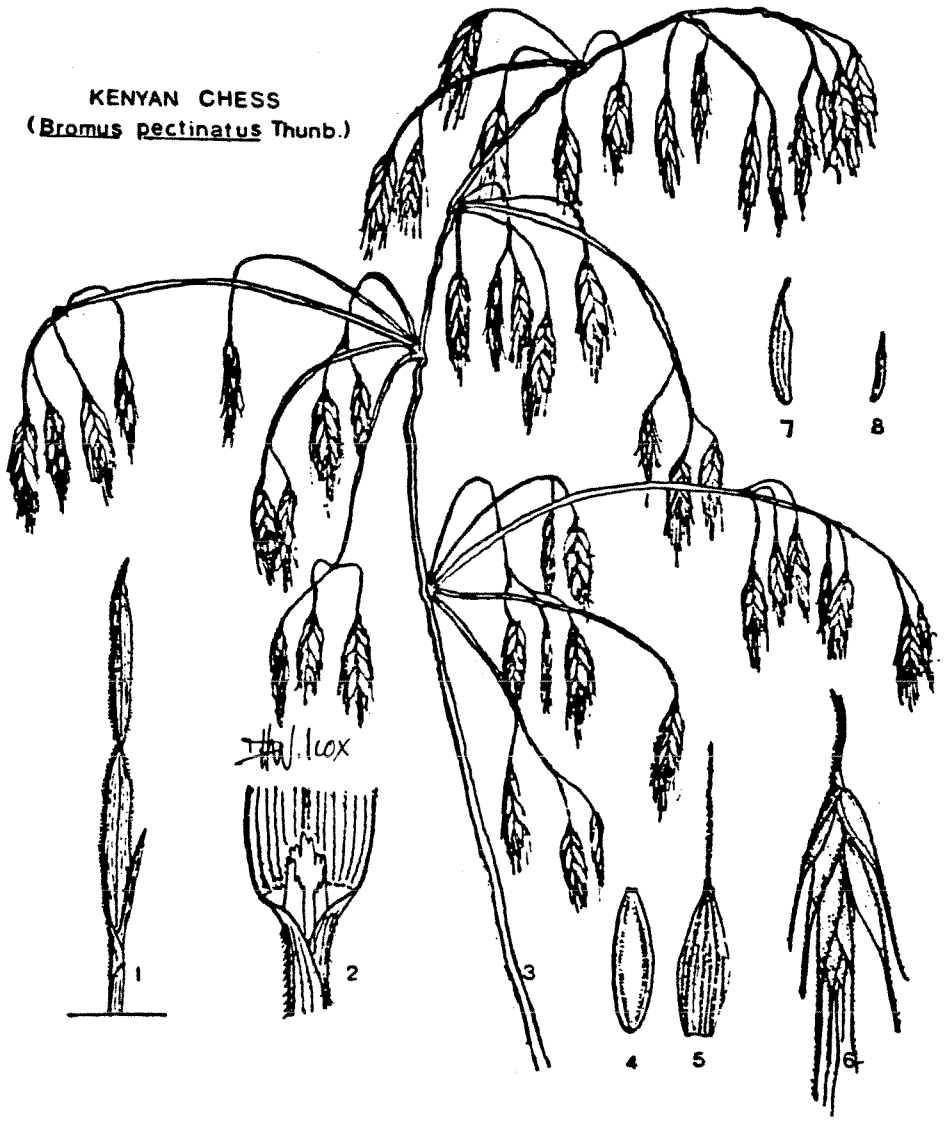


Figure 2. Bromus pectinatus - 1, seedling x 1.0; 2, ligule x 2.0; 3, inflorescence habit x 0.25; 4, palea x 2.0; 5, lemma x 2.0; 6, spikelet x 1.5; 7, upper glume x 1.0; 8, lower glume x 1.0

species that Hitchcock and Chase (1950) list in the *Bromium* group are presented in Table 1.

Fedorov (1969) states that *B. adoensis* Hochst (*B. pectinatus*) has 28 chromosomes. Table 1 lists the chromosome numbers of Hitchcock and Chase's (1950) *Bromium* group as they are given in Fedorov (1969). Only some members of this *Bromium* group contain 28 chromosomes. They are *B. mollis*, *B. secalinus*, *B. racemosus*, *B. commutatus*, *B. brizaeformis* and *B. arenarius*. It is these species which are most closely allied to *B. pectinatus*.

The conclusion that these species are closely allied with *B. pectinatus* has some basis in the literature. Clayton (1971) suggests that *B. arenarius* is probably not distinct from *B. pectinatus*. Hitchcock and Chase (1950) suggest that *B. commutatus*, *B. mollis*, *B. racemosus* and *B. secalinus* are closely allied, differentiated only by arbitrary characters, and Hulbert (1955) suggests that they may even all belong to one species.

Kenyan Chess

Table 1 lists the common names of many members of the *Bromium* group. They all include the word Chess in their name. In Kenya there are two weedy *Bromus* species, *B. diandrus* and *B. pectinatus* (Clayton, 1971). However, in Kenya there is only one common name used for both - bromegrass. These two *Bromus* species are distinct and one, *B. pectinatus*, is more of a weed than the other. The common name of *B. diandrus* in the U.S.A. is ripgut grass (Hitchcock and Chase, 1950) but there is no common name for *B. pectinatus*. It is proposed that the common name "Kenyan Chess" be assigned to *B. pectinatus*, following the

Table 1. Scientific name, common name and chromosome numbers of members of the *Bromium* group of genus *Bromus* (Hitchcock and Chase, 1950; Fedorov, 1969).

Scientific Name	Common Name	Chromosome Number (2n)
B. arenarius Labill	Australian Chess	28
B. arvensis L.	-	14
B. brizaeformis Fisch. and Mey.	Rattlesnake Chess	28
B. commutatus Schrad.	Hairy Chess	14, 28, 56
B. japonicus Thunb.	Japanese Chess	14
B. molliformis Lloyd.	-	-
B. mollis L.	Soft Chess	28
B. racemosus L.	-	28
B. secalinus L.	Chess	28 (14)
B. squarrosus L.	-	14

tradition of other members of the *Bromium* group.

CHAPTER 2

The Influence of Soil pH on the Morphology of *Bromus pectinatus* Thunb.

ABSTRACT

Bromus pectinatus Thunb. was grown in pots, in three soils, and in three environments, as well as in one soil amended over a range of pH. Plants grown in a strongly acid soil (pH = 4.8) had fewer culms, panicles and spikelets than did plants grown in moderately acid soils (pH = 5.2 and 5.7). Plants grown outdoors matured earlier, but were shorter in height and had fewer culms, panicles and spikelets than plants grown in the glasshouse or in the shade house. An acid plinthic ferrisol soil amended to a pH of 3.37 could not support growth of *B. pectinatus*. Amended to a pH of 7.55 the acid plinthic ferrisol soil could support *B. pectinatus* but the plants took longer to mature, were shorter, and had fewer culms, panicles and spikelets than plants grown in the same soil amended to pH 5.00, 6.55 and 7.15. The optimum pH for growth of *B. pectinatus* in an amended acid plinthic ferrisol is suggested to be around 6.55 as maximum culm, panicle and spikelet numbers occurred at this pH.

INTRODUCTION

Kamprath (1984) suggests that grasses adapted to the tropics, are generally very tolerant of soil acidity. *Bromus pectinatus* Thunb. is a grass native to Kenya, and a serious weed in many wheat and barley fields in the Kenyan uplands. About 30% of the wheat growing areas of

Kenya are acid plinthic ferrisols (pH 4.3 - 5.0) and the average pH of these acid soils is 4.9 (Mulamula, 1983). The barley growing regions of Kenya, which often coincide with the wheat growing regions are reported to range in pH from 4.4 to 6.1, with an average soil pH of 5.7 (Owino *et al.*, 1983).

The acid fertilizers monoammonium phosphate (11:52:0) and diammonium phosphate (11:46:0) are commonly available in Kenya (Anonymous, 1983). Use of these fertilizers may be increasing soil acidity in the traditional wheat and barley growing areas.

Increasing land subdivision into small holdings is pressuring traditional large scale cereal producers in the Kenya highlands, to move into more marginal areas (Briggs, 1983). A general movement of cereal production to more marginal areas, including areas with more acid soil, may result in a change of weed competitors in the crops.

It has been well established that weed floras are influenced by soil pH (Buchanan *et al.*, 1975). The weediness of *B. pectinatus* may be affected by soil pH, as in other *Bromus* species. For example Behrendt and Hanf (1979) stated that *B. secalinus* L. is commonly found in winter cereals on acid soils whereas *B. tectorum* L., *B. erectus* Huds. and *B. arvensis* L. are more likely to occur on alkaline soils. *B. mollis* was difficult to establish in fields with soil pH of 4.15 to 4.3 (Mott, 1962).

It is important that it be determined whether *B. pectinatus* will continue to be a serious weed in the new marginal wheat and barley production regions. Long term projections as to Kenyas future crop yields, and input (herbicides, soil amendments) requirements can then be more accurately predicted.

The objectives of these experiments were to observe the growth of *B. pectinatus* on three Kenyan soils, and on an acid plinthic ferrisol amended to a range of pH. An experiment was also conducted using three populations of *B. pectinatus*, from Kenya, to determine if there were any differences in growth and development. Subspecies would be expected to show independent marked variation in growth form and/or internal biochemistry in response to certain aspects of their environment (Aldrich, 1984).

MATERIALS AND METHODS

Soil was collected from fields at the Agricultural Experimental Farm, Eldoret; the Kenya Breweries Ltd. Research Station, Mau Narok; and the National Plant Breeding Station, Njoro. The soil was collected from the 5 to 25 cm depth during September 1982, and placed in dry storage, in gunny bags, until used. Soil samples were sent to the National Agricultural Laboratories, Nairobi, for analysis. The results of the soil analysis are presented in Table 2.

Seed samples of *B. pectinatus* were hand stripped from mature plants growing near the Njoro soil collection site, on September 16, 1982, and near the Mau Narok soil collection site on December 1, 1982. The Eldoret soil collection site had no *B. pectinatus* present so *B. pectinatus* samples were hand stripped from mature plants on November 30, 1982, at the Kruger farm, Sergoit Rock, a site which had a soil pH of 5.4, and was located 12 km from the Eldoret soil collection site. All collected seed was air dried and stored in opaque air tight plastic containers in the laboratory.

Table 2. Description of soil types.

Site :		ELDORET	MAU NAROK	NJORO
Altitude (Metres) :		2150	2835	2165
Climate Class :		Semi-humid	Sub-humid	Semi-humid
Soil Texture : %sand/%silt/%clay :		Clay Loam 32/38/30	Loam 32/44/24	Clay Loam 36/30/34
Soil pH (H_2O, 1:1) :		4.8	5.2	5.7
Exchangeble Acidity (Hp m.e.%) :		0.6	0.3	-
Available Nutrients	Total N% :	0.18	0.43	0.24
	P "Mehlich" ppm :	18	15	12
	K m.e. % :	1.43	1.22	2.00
	Ca m.e. % :	2.8	8.0	4.4
	Na m.e. % :	0.09	0.16	0.12
	Mn m.e. % :	0.98	0.90	1.40
Organic Matter (C %) :		2.00	4.02	2.14

General Procedures

These experiments were all conducted at the National Plant Breeding Station, Njoro, under three growth environments. These environments were the out-of-doors, a shadehouse (an opaque fiberglass roofed, open sided, structure) and a glasshouse.

Soil was added to 20 cm diameter, 4 liter plastic pots, and uniformly compacted. Five seeds were placed 1 to 2 cm deep into the soil. After the seeds had emerged they were thinned to one plant per pot. Pots were observed on a daily basis and were watered as necessary to maintain healthy growth. No fertilizers or supplementary lighting was used.

At maturity (>95% of the plants senescent) the plants were evaluated for plant height (from soil surface to tip of the highest spikelet when plant held erect), number of culms, number of spikelets and number of panicles. The number of days from planting until the first panicle emerged was also recorded. The average number of spikelets per panicle is the result of dividing the spikelets per plant by the panicles per plant.

This data was analysed by ANOVA and tests for significance conducted using the least significant difference (LSD) test. Only differences found by the LSD test at the 5% significance level were considered meaningful.

Experiment 1(a). The effect of soil type and environment on growth of three sources of *Bromus pectinatus* Thunb.

Seed from each of the three seed sources was sown February 21, 1983, into each of the three soil types for a total of 9 treatments. These treatments were grown in a randomized complete block design with four replicates in the three growth environments. Plants were evaluated on July 20, 1983, when all plants were considered mature.

Experiment 1(b). The effect of soil type and environment on growth of *Bromus pectinatus* Thunb.

This experiment is similar in design to Experiment 1(a), with 4 replicates, but only the Njoro seed source was sown in the three soils. This gave a total of three treatments, instead of the nine in Experiment 1(a).

Experiment 1(b) was sown on June 29, 1983, and evaluation of mature plants grown out-of-doors and in the shadehouse were made December 1, 1983. Glasshouse grown plants were evaluated on January 24, 1984.

Experiment 2. The influence of amending an acid plinthic ferrisol on growth of *Bromus pectinatus* Thunb.

In this experiment, soil collected at Eldoret, an acid plinthic ferrisol, had its pH modified using concentrated H_2SO_4, to lower pH, and 74% $Ca(OH)_2$ powder, to raise soil pH. The amended soil was conditioned for a period of 45 days by putting the soil through alternating cycles of wetting and drying. Samples of the amended soil were taken before and after the experiment and the average pH recorded as the treatment pH. The treatment pH were 3.37, 5.00, 6.55, 7.15 and 7.56. The amended soils were then divided among the replicates and placed in pots arranged in a 5x5 latin square design in the shadehouse. The Sergoit Rock

collected *B. pectinatus* seed was sown into these pots on July 21, 1983, and evaluation of mature plants conducted on January 4, 1984.

RESULTS AND DISCUSSION

There were fewer culms, panicles and spikelets produced on *B. pectinatus* plants grown in soil from Eldoret than the plants grown on Mau Narok and Njoro soils (Tables 3, 4, 5 and 6). Plant height, days to first panicle emergence, and spikelets per panicle of plants grown in the Eldoret soil was not significantly different from plants grown in the Mau Narok and Njoro soil. It appears that in *B. pectinatus* plant height, days to first panicle emergence and spikelets per culm are less subject to variation due to edaphic factors than are culm number and panicle number.

From the description of the soil (Table 2) it is apparent that the major difference in soil properties between the soil from Eldoret and the soils from Mau Narok and Njoro is that the Eldoret soil is more strongly acid than the other two. It is difficult for plants to survive in strongly acid soils because acid soils often induce nutrient deficiencies and/or elemental toxicities (Follett *et al.*, 1981). Owino *et al.*, (1983) suggests the main reasons for difficulty in growing barley in low pH soils in Kenya are applied phosphate fixation and accumulation of aluminum and iron to phytotoxic levels.

Eldoret soil was lower in nitrogen than the other two soils. The low nitrogen may have reduced culm production in the *B. pectinatus* plants grown in this soil. Low nitrogen levels in the soil appear to

Table 3. Pot growth of three Bromus pectinatus Thunb. seed sources grown in three soils out-of-doors at the NPBS Njoro, Kenya.

SOURCE[1] SEED	SOURCE[2] SOIL	PLANT HEIGHT (cm)	DAYS TO FIRST PANICLE EMERGENCE	CULMS PER PLANT	SPIKELETS PER PLANT	PANICLES PER PLANT	SPIKELETS PER CULM
MN	MN	52.0 abc[3]	88.3 c	14.0 a	350.0 a	13.0 ab	27.0 a
N	MN	53.3 abc	89.5 c	14.5 a	347.3 a	13.0 ab	26.8 a
SR	MN	55.5 ab	89.5 c	15.3 a	347.8 a	13.0 ab	27.0 a
MN	N	60.5 a	94.8 c	11.0 b	293.8 a	11.0 b	26.5 a
N	N	58.3 a	92.3 c	13.8 a	323.0 a	13.3 a	24.5 ab
SR	N	53.3 abc	90.8 c	13.8 a	325.5 a	12,5 ab	25.8 a
MN	E	47.0 c	120.5 a	2.5 c	30.0 b	2.3 c	13.5 c
N	E	45.3 c	118.3 a	3.0 c	53.8 b	3.0 c	18.0 bc
SR	E	48.5 bc	108.3 b	3.3 c	87.0 b	3.3 c	27.0 a
AVERAGE		52.6	98.0	10.1	239.8	9.4	24.0
$LSD_{.05}$		9.2	9.8	2.5	60.6	2.1	6.7
C.V.		12	7	17	17	16	19

[1] Seed Sources : MN = KBL research station Mau Narok, N = NPBS Njoro, SR = Sergoit Rock Eldoret.

[2] Soil Sources : MN = KBL research station Mau Narok, N = NPBS Njoro, E = AEF Eldoret

[3] Numbers in the same column followed by the same letter do not differ significantly ($P \geq .05$) according to the LSD test.

Table 4. Pot growth of three Bromus pectinatus Thunb. seed sources grown in three soils in the shadehouse at the NPBS Njoro, Kenya.

SOURCE[1] SEED	SOIL[2]	PLANT HEIGHT (cm)	DAYS TO FIRST PANICLE EMERGENCE	CULMS PER PLANT	SPIKELETS PER PLANT	PANICLES PER PLANT	SPIKELETS PER CULM
MN	MN	60.5 ab[3]	93.5 c	13.5 a	324.5 b	12.8 b	25.8 abc
N	MN	59.3 ab	107.5 abc	15.5 a	370.8 ab	13.8 ab	27.3 a
SR	MN	60.8 ab	103.0 bc	15.8 a	345.3 ab	15.0 ab	23.0 bc
MN	N	67.0 a	112.3 abc	15.0 a	401.3 a	14.5 ab	28.0 a
N	N	67.8 a	100.3 c	14.8 a	371.3 ab	13.8 ab	26.8 ab
SR	N	68.3 a	102.0 bc	15.8 a	405.3 a	15.5 a	26.5 ab
MN	E	56.8 b	122.3 ab	4.5 b	79.0 c	4.3 c	18.8 d
N	E	62.5 ab	113.5 abc	4.5 b	100.0 c	4.5 c	21.8 cd
SR	E	61.5 ab	127.8 a	3.0 b	90.3 c	3.0 c	29.0 a
AVERAGE		62.7	109.1	11.8	276.4	10.8	25.2
$LSD_{.05}$		9.2	20.6	3.1	65.2	2.5	4.1
C.V.		10	13	19	16	16	11

[1]Seed Sources : MN = KBL research station Mau Narok, N = NPBS Njoro, SR = Sergoit Rock Eldoret.

[2]Soil Sources : MN = KBL research station Mau Narok, N =NPBS Njoro, E = AEF Eldoret.

[3]Numbers in the same column followed by the same letter do not differ significantly ($P \geq .05$) according to the LSD test.

Table 5. Pot growth of three Bromus pectinatus Thunb. seed sources grown in three soils in a glasshouse at the NPBS Njoro, Kenya.

SOURCE[1] SEED	SOIL[2]	PLANT HEIGHT (cm)	DAYS TO FIRST PANICLE EMERGENCE	CULMS PER PLANT	SPIKELETS PER PLANT	PANICLES PER PLANT	SPIKELETS PER CULM
MN	MN	76.0 b[3]	117.0 bc	14.5 abc	372.0 ab	13.5 bc	28.3 c
N	MN	77.3 b	117.0 bc	16.3 ab	407.3 ab	14.3 abc	28.5 c
SR	MN	79.0 ab	111.8 c	17.3 a	430.8 a	16.0 a	27.3 c
MN	N	80.3 a	125.5 bc	15.5 abc	388.3 ab	14.5 ab	26.8 c
N	N	76.3 b	122.0 bc	12.8 c	354.5 b	12.3 bc	29.3 bc
SR	N	74.8 b	118.5 bc	13.3 bc	352.5 b	12.0 c	29.8 bc
MN	E	75.8 b	127.0 b	4.0 d	133.0 c	3.3 d	36.5 abc
N	E	87.8 a	144.5 a	4.0 d	153.3 c	4.0 d	39.5 ab
SR	E	77.5 b	123.5 bc	5.0 d	168.5 c	4.3 d	43.8 a
AVERAGE		78.3	123.0	11.4	306.7	10.5	32.2
$LSD_{.05}$		9.0	14.2	3.0	70.9	2.3	10.8
C.V.		8	8	18	16	15	23

[1]Seed Sources : MN = KBL research station Mau Narok, N = NPBS Njoro, SR = Sergoit Rock Eldoret.

[2]Soil Sources : MN = KBL research station Mau Narok, N = NPBS Njoro, E = AEF Eldoret

[3]Numbers in the same column followed by the same letter do not differ significantly ($P \geq .05$) according to the LSD test.

Table 6. Pot growth of Njoro source Bromus pectinatus Thunb. grown in three soils in three environments.

ENVIRONMENT[1]	SOIL SOURCE[2]	PLANT HEIGHT (cm)	DAYS TO FIRST PANICLE EMERGENCE	CULMS PER PLANT	SPIKELETS PER PLANT	PANICLES PER PLANT	SPIKELETS PER CULM
O	MN	93.0 e[3]	63.5 d	14.3 b	300.0 c	13.3 bc	23.0 bcd
O	N	94.7 de	61.0 d	16.8 ab	367.0 bc	18.3 a	20.3 cd
O	E	55.7 f	78.3 c	2.5 c	20.0 d	1.5 d	12.5 d
S	MN	109.3 bc	75.3 c	19.3 ab	610.5 a	17.8 ab	43.8 a
S	N	102.0 cd	74.5 c	18.8 ab	493.0 ab	18.5 a	34.0 ab
S	E	92.7 e	76.8 c	5.5 c	84.3 d	4.8 d	15.5 cd
G	MN	113.7 b	123.0 a	16.8 b	312.8 c	12.5 c	25.3 bc
G	N	109.0 bc	107.8 b	22.5 a	338.5 bc	14.5 abc	24.0 bcd
G	E	123.0 a	113.8 b	5.3 c	138.0 d	4.3 d	34.5 ab
AVERAGE		99.3	86.0	13.8	296.0	11.7	25.9
$LSD_{.05}$		8.9	8.7	5.3	156.7	4.6	11.6
C.V.		8.0	6.8	25.9	35.6	26.2	2.5

[1] Environments : O =out-of-doors, S = shadehouse, G = glasshouse

[2] Soil Sources : MN = KBL research station Mau Narok, N = NPBS Njoro, E = AEF Eldoret

[3] Numbers in the same column followed by the same letter do not differ significantly ($P \geq .05$) according to the LSD test.

minimize the phytotoxic effect of soil acidity. High rates of N can replace Al^{+} from the soil exchange sites and increase the phytotoxicity of an acid soil (Kamproth, 1984).

Out-of-doors grown *B. pectinatus* plants consistantly had the shortest plants, the least number of culms, panicles and spikelets per panicle relative to plants grown in the shadehouse or glasshouse (Tables 3, 4, 5 and 6). Out-of-doors grown plants generally began panicle emergence earlier than did shadehouse or greenhouse grown plants. Glasshouse grown plants, in general, took the longest to mature, were the tallest, and often had the most spikelets per plant.

At an altitude of 2500 m the average Kenyan wheat variety takes 130 days to mature and the average Kenyan barley variety 149 days to mature (Anonymous, 1984). It took the *B. pectinatus* grown in these experiments from 61 (Table 6) to 145 days (Table 5) for the first panicles to emerge, with the overall average being 104 days. Thus, the majority of the *B. pectinatus* plants have panicles which emerge well before the crop has matured.

There were no significant trends observed in relation to seed source. *B. pectinatus* seed origin (Mau Narok, Njoro or Sergoit Rock) had no influence on plant height, first panicle emergence, culms per plant, spikelets per plant, panicles per plant, or spikelets per culm (Tables 3, 4 and 5). There was much more variation within the seed populations, than between the seed populations, despite having been grown in many different environmental combinations. This lack of variation in seeds from different sites implies that the three seed sources are one species and that none of these three were a distinct subspecies of *B. pectinatus*. Subspecies would vary markedly in growth

form and/or internal biochemistry (Aldrich, 1984). The possibility that there may be a subspecies of *B. pectinatus* on an internal biochemistry basis was not investigated in these experiments.

Experiment 1(a) and 1(b) were conducted on soils which ranged in pH from 4.8 to 5.7. On these soils, soil pH influenced the number of culms, panicles and spikelets per plant. Experiment 2 was conducted on soils of a broader pH range, from 3.37 to 7.56. Over the broader pH range, plant height, days to panicle emergence, and the number of spikelets per culm were also affected (Figure 3).

The acid plinthic ferrisol soil from Eldoret, amended to pH 3.37 did not allow germination or growth of *B. pectinatus* (Figure 3). Even *B. pectinatus* seedlings transplanted, in the one to two leaf stage, into the pots with this soil, did not survive.

B. pectinatus plants, grown in pots containing the acid plinthic ferrisol amended to pH 7.56, was shorter (Figure 3A), had fewer culms (Figure 3C), fewer panicles (Figure 3E), fewer spikelets (Figure 3D and 3F) and took longer to mature (Figure 3B), than any of the other surviving treatments. Optimum growth of *B. pectinatus* occurred when the acid plinthic ferrisol was amended to pH 6.55. At the pH of 6.55, number of culms, spikelets and panicles were the highest of all the treatments, whereas, plant heights, days to first panicle emergence and spikelets per culm were not different from the other surviving acid soil treatments. Despite the best weedy growth of *B. pectinatus* at a pH of 6.55 this pH should not be considered the optimum for all soils.

Buchanan *et al.* (1975) demonstrated that it is not possible to define critical soil pH values for any plant species except for a particular soil. Soil fertility, soil organic matter and amount of

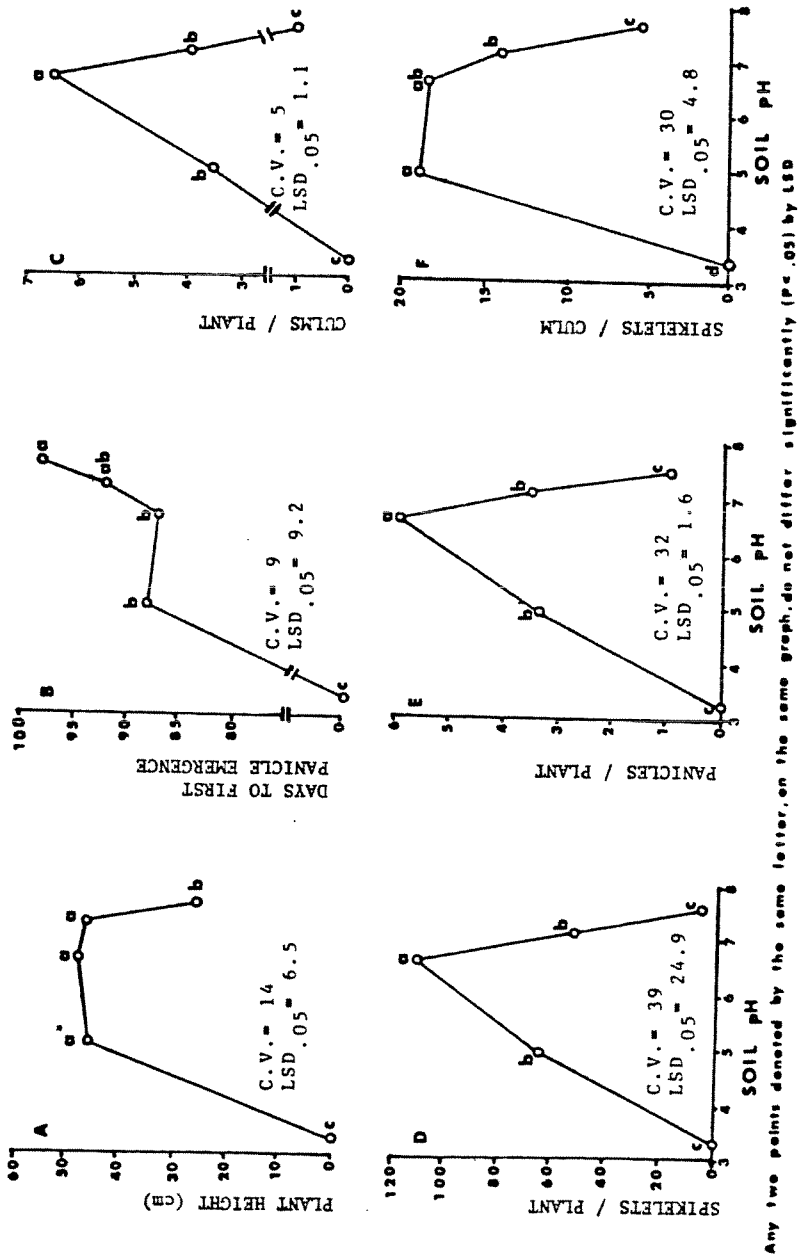


Figure 3. The influence of soil pH on Bromus pectinatus Thunb. plant height (A), days to first panicle emergence (B), culms per plant (C), spikelets per plant (D), panicles per plant (E), spikelets per culm (F).

competition can influence plant response to soil pH. High rates of nitrogen and potassium can replace aluminum from the soil and increase the phytotoxicity of an acid soil (Kamprath, 1984). Increasing the level of soil organic matter will allow plants to be more tolerant of soil acidity (Follett *et al.*, 1981). Competition can shift the optimum pH for growth of some species (Barbour *et al.*, 1980). In Experiment 2 the plants were grown in pots under no competition.

Kamprath (1984) suggests that in acid tropical soils primary consideration must be given to removing the soil acidity factors limiting growth, rather than liming to increase soil pH. Use of acid fertilizers, such as DAP and MAP, may actually help to reduce the weediness of *B. pectinatus*, by increasing soil acidity which can be antagonistic to *B. pectinatus*.

At slightly alkaline pH (pH 7.56) the growth of *B. pectinatus* was inhibited (Figure 3). With liming materials readily available in Kenya (Mulamula, 1983) it might be possible to lime slightly acid soils to a slightly alkaline pH which may reduce the competitiveness of *B. pectinatus* against crops growing in this soil.

Soil pH does have an effect on weediness of *B. pectinatus*, but whether this effect can be used as a control measure has yet to be determined. Potential difficulties with modifying soil pH include the cost of the soil amendments, the time required to achieve change, and changes in persistance and efficacy of soil applied herbicides (Walker and Buchanan, 1982).

CHAPTER 3

Factors Influencing the Germination and Emergence of *Bromus pectinatus* Thunb.

ABSTRACT

Studies were conducted on the influence of seeding depth, soil pH, seed numbers, light, temperature, afterripening and seed treatment on the germination of *Bromus pectinatus* Thunb. It was observed in a clay loam soil that germination was unaffected by depth of burial while emergence was reduced to 35, 19, 11, 4 and 0% from depths of 0, 1, 2, 4 and 8 cm, respectively. An acid plinthic ferrisol, amended to various pH could not support germination at a pH of 3.05, but did allow 51% or better germination at soil pH ranging from 3.85 and 8.13. There was an optimum pH for germination at pH 5.5 to 6.0. Caryopsis germination in a 9 cm petri dish was found to be best at 40 seeds or less per dish, while at greater numbers, to 100 seeds per dish, there was an inverse relationship between seed number and germination. Fluorescent light was found to inhibit germination. Optimum temperature for germination was determined to be 17 C. Prechilling the seed, under moist conditions, at 3 C or preheating at 60 C had no beneficial effect on germination. In freshly harvested seed, removing the lemma and palea, pricking the lemma, and removing the rachilla segment were found to enhance germination.

INTRODUCTION

Bromus pectinatus Thunb. is a native annual grass of East Africa (Clayton, 1973) and is a major weed of wheat and barley grown in the Kenyan uplands. Control of *B. pectinatus* in wheat and barley has only

been partially successful with herbicides. The limited success with herbicides necessitated the development of other management techniques for the control of *B. pectinatus*. Studies on the germination and emergence of *B. pectinatus* were conducted to indicate which cultural and mechanical practices would be expected to reduce *B. pectinatus* germination and emergence. As stated by Anderson (1983): "It is necessary to understand what is occurring below the soil surface with respect to weed seeds and seedlings if one is to undertake control of weed seeds in a knowledgeable manner ".

Large scale wheat and barley farmers in the traditional growing areas of Kenya are being pressured to give up their land for subdivision and move their operations to more marginal areas of production (Briggs, 1983). For long-term agricultural planning it is important that it be determined whether *B. pectinatus* will continue to be a major weed of wheat and barley in these new production areas.

B. pectinatus became important as a weed of wheat fields in Kenya with successful control of other weeds (Mulamula, 1983). However, *B. pectinatus* now persists as a major weed of wheat even in fields where other weeds are not controlled. At present *B. pectinatus* is only a weed in East Africa and Turkey (Pollard *et al.*, 1984) but through spread of contaminated crop seed *B. pectinatus* could spread to other countries.

The objective of this study was to understand the germination and emergence requirements of *B. pectinatus* in order to determine which management techniques for *B. pectinatus* suppression could be successful and to assess its potential for spread. No studies on *B. pectinatus* germination or emergence requirements were found in the literature.

MATERIALS AND METHODS

Three sources of *B. pectinatus* seeds were used in these studies. Seeds were hand stripped from mature panicles of *B. pectinatus* at the National Plant Breeding Station, Njoro, on September 16, 1982 (NPBS 82) and on September 19, 1983 (NPBS 83) as well as at the Kenya Breweries Ltd. Research Station, Mau Narok, on December 23, 1982 (KBL 82). Collected seeds were air dried and then placed in airtight glass jars which were stored in the agronomy lab until used. The National Plant Breeding Station, is located at an altitude of 2165 m and has a semi-humid climate. Whereas, the Kenya Breweries Ltd. Research Station is at an altitude of 2835 m and has a sub-humid climate.

Germination studies were primarily conducted in a germinator (Cleland International, Inc. Model 500L). The germinator was kept dark, except in the effect of light experiment, and maintained at a constant high humidity and at a constant temperature of 20 C.

Seeds were germinated in 9 cm petri dishes which contained two sheets of Whatman number 1 or 2 filter paper to which was added 5 ml of distilled water. Seeds placed on the filter paper were uniformly spatially separated and were aligned so that they all faced the same direction in the dish. Dishes were examined at 7 day intervals and germinated seeds counted and removed. Germination was defined as emergence of the radicle from the seed for a length greater than 5 mm.

A randomized complete block design was used in the experiments. Germinator experiments had the replicates spatially separated on the germinator shelves. Before analyses by the analyses of variance all germination data was transformed using the arc sin $\sqrt{x}$ to adjust the

data to appear as a normally distributed population. Data was then analysed using the least significant difference test. Only data which varied at the 5% significance level was considered meaningful.

Effect of Soil pH on Germination of *Bromus pectinatus* Thunb.

This study was conducted three times, twice with hulled seed (NPBS 82) and once with dehulled seed (NPBS 82). In this study an amended acid plinthic ferrisol soil was used as the germination media. Soil pH greater than 4.92 was achieved by amending the soil with 74% $Ca(OH)_2$ powder. Soil pH less than 4.92 was achieved by amending with conc. H_2SO_4. Amended soils were conditioned before use by subjecting the soils to at least three major wetting and drying cycles, in a glasshouse, over a period of 1 month. Soil pH values were determined from soil samples taken before soil was added to the petri dishes.

Thirty grams of soil at the required pH (pH range 3.05 - 7.56) was added to each petri dish. One sheet of Whatman number 2 filter paper was placed to each petri dish. Twenty ml of distilled water was then added to each petri dish. A control treatment, consisting of two discs of Whatman number 2 filter paper and 5 ml of distilled water was included. The distilled water used in the trials ranged in pH from 6.8 to 7.4

Thirty dehulled seeds were placed into each dish, on top of the filter paper. Four replicates of each treatment were placed in the germinator. Dehulled seeds were used in the trials placed in the germinator on April 13, 1983 and on August 30, 1983. Hulled seeds were used in the trial placed in the germinator on September 15, 1983. All 3

experiments were run for 14 days.

Effect of Seed Number Per Petri Dish on Germination of *Bromus pectinatus* Thunb.

Dehulled seed (NPBS 82) was used in this experiment. The treatments used were 20, 40, 60, 80 and 100 seeds per dish. Seed was arranged in a grid pattern that maximized the distance between seeds in the dish. To compensate for the greater number of seeds in some treatments, 6 ml of distilled water was added to each petri dish. The eight replications of the treatments were placed in the germinator on March 24, 1983. The experiment was run for 21 days.

Effect of Light on Germination of *Bromus pectinatus* Thunb.

Collected seed (NPBS 82) was split into two batches. One batch of seed was stored in the dark, in an office drawer. The remaining seed batch was stored in light, on an office window sill, exposed to daylight.

The germinator was illuminated continuously over the germination period by 4 cool white fluorescent tubes along the back of the germinator. The dark germinated treatments were placed in the same germinator as the light treatments, but had their petri dishes enveloped with aluminum foil. The seed was placed in the germinator on December 10, 1982, and the trial discontinued 14 days later.

Each treatment consisted of 20 seeds per petri dish in six replications. Treatments consisted of light stored seed being dehulled and then germinated in the light and dark, and dark stored seed, both

hulled and dehulled, germinated in the light and dark.

Effect of Temperature on the Germination of *Bromus pectinatus* Thunb.

This trial was conducted using a thermal gradient plate. The thermal gradient plate was a brass plate which was heated along one side and cooled along the other, establishing a thermal gradient across the plate. The plate was inside a styrofoam box and centrally placed thermocouples were used to monitor temperature at each of the 8 germination temperatures used. The treatment temperatures used in this trial were 1, 3, 8, 12, 17, 22, 28 and 32 C. The plate design was based on the concepts and equipment of other researchers such as Wagner (1967), Chatterton and Kadish (1969) and Clegg and Eastin (1978).

Seed germination was conducted in germination boxes. Each germination box was made of clear plastic and had the dimensions 2 cm x 2 cm x 6 cm. Each germination box contained two sheets of number 5 Whatman filter paper, moistened with 0.6 ml of distilled water. Ten hulled seeds (NPBS 82) were placed on top of the filter paper. The boxes were then sealed with parafilm and their fitted lids, and placed on August 22, 1984, in a column over each of the eight gradients monitored by thermocouples. The entire plate area was then covered with styrofoam chips and a thermo-aluminum blanket. Every 5 days the germinated seeds were counted and discarded. The trial was discontinued after 15 days.

Effect of Seed Afterrippening Treatments on Germination of *Bromus pectinatus* Thunb.

In this trial 4 treatments of 20 seeds each, were replicated 10 times and placed in the germinator on January 21, 1984. The treatments were prechilled seed (NPBS 83), preheated seed (NPBS 83), untreated seed (NPBS 83) and untreated older seed (NPBS 82). After 7 days in the germinator the trial was discontinued.

Prechilled seed was prepared by wrapping the seed in moist filter paper and then placing the seed in a plastic bag in a fridge (3 C) for 7 days. Preheated seed was prepared by placing dry seed into an oven (60°C) for 12 days.

Influence of the Seed Hull on Germination of *Bromus pectinatus* Thunb.

Seed germination studies were conducted in a dark laboratory drawer using hulled and dehulled seeds (NPBS 82). Hulled and dehulled seeds (KBL 82) were also germinated in the germinator. Germination studies in the laboratory drawer were initiated on 3 dates; September 23, October 21 and November 18, 1982. The germinator study was initiated on January 13, 1983. A min-max thermometer kept in the laboratory drawer over the germination interval recorded a maximum temperature of 20.1 C and a minimum temperature of 18.1 C.

Each study included three treatments; dehulled seed, dehulled seed plus loose husks, and hulled (untreated) seed. In the dehulled seed plus loose husk treatments, the lemma, palea and rachilla segments removed in dehulling the seeds were sprinkled into the petri dishes. As a result, the dehulled seed plus loose husk petri dishes had

approximately twice the hull particulate matter that was on the seed in the hulled seed treatments. Each treatment contained 20 seeds and was replicated 8 times.

Effect of Lemma Pricking and Rachilla Removal on the Germination of *Bromus pectinatus* Thunb.

In this study each treatment was carried out on twenty seeds and replicated 8 times. There were 4 treatments; pricked seeds, rachilla segment removed seeds, dehulled seeds and hulled (untreated) seeds. Pricked seeds had the center of the lemma pierced with a straight pin. The rachilla segment was hand removed as was the hull in the dehulled seed treatments. The treatments were placed in the germinator on January 13, 1983, and the study was terminated 28 days later.

Effect of Seeding Depth on Germination and Emergence of *Bromus pectinatus* Thunb.

A 2 cm deep layer of sifted clay loam soil, from the NPBS, Njoro, moistened to 90% field capacity (F.C.) was added into each 20 cm diameter, 4 liter, plastic pot. Sixty dehulled seeds (NPBS 82) were placed in the pots. Each pot then had its respective depth (0, 1, 2, 4 and 8 cm) of soil (at 90% F.C.) layered over the seed.

Pot mouths were then sealed with a 2 mm thick sheet of clear plastic. The clear plastic allowed light to enter the pots while maintaining moisture for the duration of the experiment.

Each treatment was grown out in a shadehouse in a randomized complete block design with 4 replicates.

The study was initiated March 23, 1983, and completed 46 days

later, on May 9, 1983. On completion, the sheet of clear plastic was removed from the pot mouths, and the number of emerged seedlings noted. The soil from each pot was then carefully washed through a 2 mm diameter sieve using running water and the *B. pectinatus* seeds were collected. Collected seeds were classified as either germinated or ungerminated. The number of emerged, germinated and ungerminated seeds were expressed as a percentage of total recovered seeds.

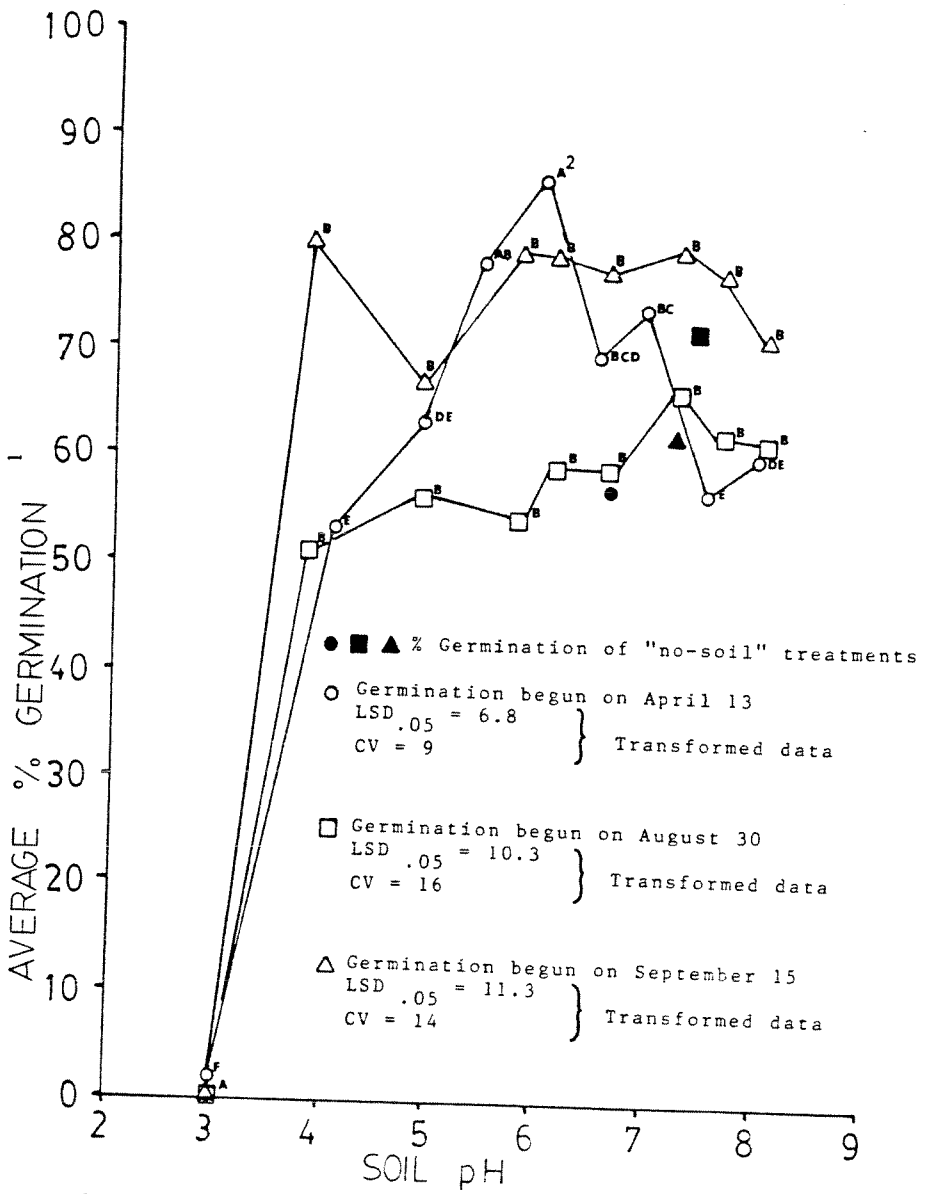
RESULTS AND DISCUSSION

Effect of Soil pH on Germination of *Bromus pectinatus* Thunb.

B. pectinatus did not germinate on an acid plinthic ferrisol with a pH of 3.05 but did have 51%, or better germination when the soil pH ranged from 3.85 to 8.13 (Figure 4). *B. pectinatus* germinated on April 13 appears to have an optimum pH for germination in the range of pH 5.5 to 6.0. Whereas, *B. pectinatus* germinated on August 30 and September 15 did not have any optimum pH for germination.

The difference between the first and the last two dates for germination, in an optimum pH, may be due to maturation of the seed. By the time of the last two trials, the seed was fully matured, whereas, the first trial may have been conducted with immature seed. The soil pH may have acted on the seed dormancy of immature *B. pectinatus*. It would normally be expected that soil pH would only become important, except at the extremes, once the radicle became active in uptake of nutrients.

Seeds germinated on April 13 and August 30 had their lemma and palea removed, seed germinated on September 15 had the lemma and palea



[1]average of 4 replicates, 30 seeds each

[2]The graph points followed by the same letter, on the same germination date, do not differ significantly ($P \leq .05$) by the LSD test.

Figure 4. The influence of amending the pH of an acid plinthic ferrisol on the germination of Bromus pectinatus Thunb. .

intact. Leaving the hulls on the seed may have increased the percentage germination over the range of pH in this study (Figure 4).

Germination of *B. pectinatus* in petri dishes without any soil was of the same general magnitude as the petri dish treatments containing soil (Figure 4). This similarity implies that this system of germinating with soil was comparable to standard germination methods.

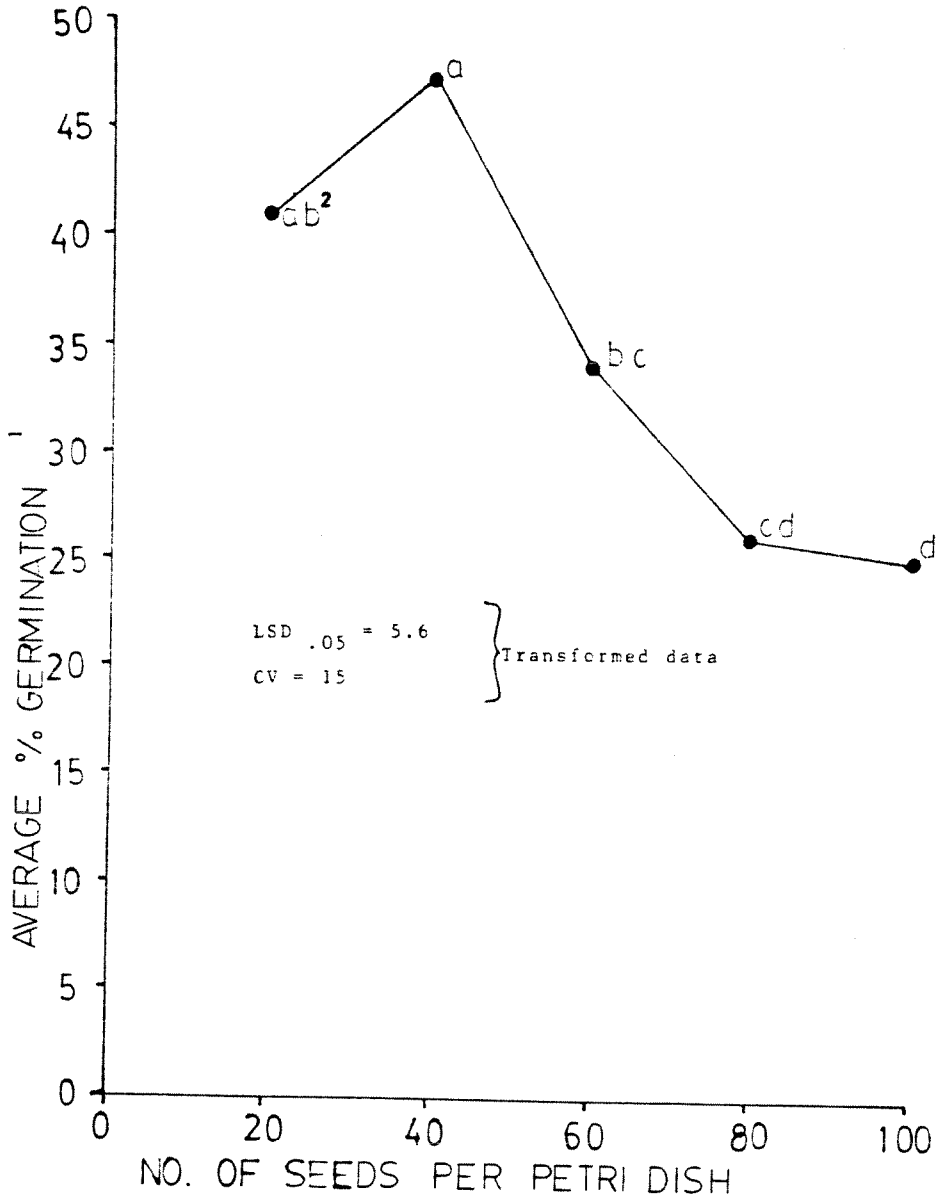
B. pectinatus germination was greater than 50%, even at pH 4.3, (Figure 4) which is the pH of the most acid soil on which wheat is grown in Kenya (Mulamula, 1983). Thus, the ecological significance of soil pH on germination, and thus weediness, of *B. pectinatus* is not likely to be significant.

Effect of Seed Number Per Petri Dish on Germination of *Bromus pectinatus* Thunb.

Laboratory germination of *B. pectinatus* is influenced by the number of seeds in the petri dish. The highest percentage germination occurred when 20 to 40 seeds were placed in a petri dish (Figure 5). At 60, 80 and 100 seeds per dish there was an inverse relationship between seed number and germination.

These results are in agreement with Palmblad (1968) who observed in *B. inermis* that increasing seed number had an effect on germination. However, he observed no effect in *B. tectorum*.

At seed numbers of 60 or more per petri dish a germination inhibitor may leach from the caryopsis of *B. pectinatus* and build up enough concentration in solution to inhibit overall germination. A negative response to seed density has been suggested by Linhart (1976) to be a population regulating mechanism likely involving germination inhibitors.



[1] average of 8 replicates, 30 seeds each

[2] Graph points followed by the same letters do not differ significantly ($P \leq .05$) by the LSD test.

Figure 5. The influence of petri dish caryopsis density on the germination of Bromus pectinatus Thunb. .

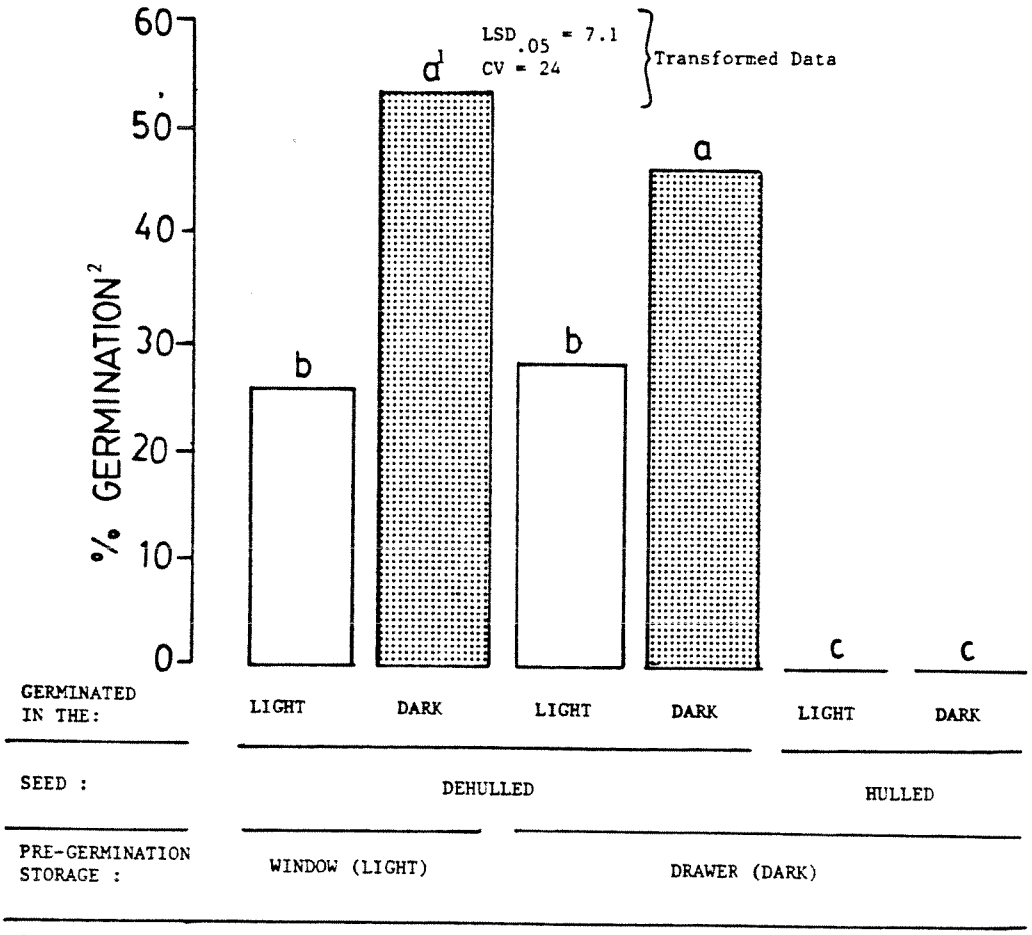
The results indicate that in laboratory germination of *B. pectinatus*, the maximum number of seeds in a 9 cm petri dish should not exceed 40.

Effect of Light on Germination of *Bromus pectinatus* Thunb.

Dry storage for 3 months in a window sill (light) or storage in a drawer (dark) made no difference in ultimate *B. pectinatus* germination (Figure 6). The results are in agreement with Anderson (1983) who states that dry seeds are known not to respond to light.

Light influenced the germination of dehulled *B. pectinatus* seeds. Exposure to fluorescent light during germination reduced germination of dehulled *B. pectinatus* by 40 to 50% (Figure 6). These results are in agreement with Hulbert (1950) who determined that recently harvested seeds of several *Bromus* sp. could be inhibited by fluorescent light. He also showed that in *B. tectorum* this light inhibition could be increased by germination at unfavorable temperature, increasing the length of daily exposure, and using daylight instead of fluorescent light. He also observed that older seeds were not influenced by light. Under conditions other than those used in this study, the observed inhibition by light might be greater.

In *B. sterilis*, light, and more specifically red light, inhibits germination (Hilton, 1984a and b). *B. sterilis* is unusual in that, unlike in most plants, the "active form" of phytochrome (Pfr) inhibits germination (Bartley and Frankland, 1984). Far red light encourages germination of *B. sterilis*. As a result *B. sterilis* is encouraged to germinate in the shade of other plants because it is primarily far red



[1]Bars topped with the same letter do not differ significantly ($P < .05$) by the LSD test.
[2]Average of 6 replicates, 20 seeds each

Figure 6. The influence of continuous fluorescent light on the germination of *Bromus pectinatus* Thunb..

light which passes through leaves. *B. pectinatus* may be affected by light through a similar mechanism.

Hulled seeds failed to germinate while dehulled seeds had at least 26% germination (Figure 6). The seeds were harvested 3 months earlier and the hulled seeds apparently still contained an innate domancy that was unaffected by germination in the light or dark.

Effect of Temperature on the Germination of *B. pectinatus* Thunb.

Based on radicle and plumule growth, the most rapid germination of *B. pectinatus* occurred at a temperature of 17 C (Figure 7). Within 15 days of initiation of the study, germination occurred at temperatures as low as 3°C and as high as 28 C. No germination occurred at 1 C or 32 C within the 15 days of the study. At 17 and 22 C most of the seeds had germinated within 5 days. Within 10 days most seeds had germinated in the temperature range 8 to 22 C.

At the highest temperatures tested (28 and 32 C), there was a problem with moisture evaporation in the germination boxes. The parafilm did not adequately seal the boxes at these higher temperatures. The low moisture may have contributed to low germination at these temperatures.

Moisture can be very important in germination. Thill *et al.* (1979) observed that at 0 bars water matric potential the optimum temperature for *B. tectorum* was 15 to 20 C, but at other levels of matric potential was 10 to 20 C. For *B. pectinatus* it has been observed by the author that soil moisture in a clay loam must be at least 50% field capacity for germination to occur.

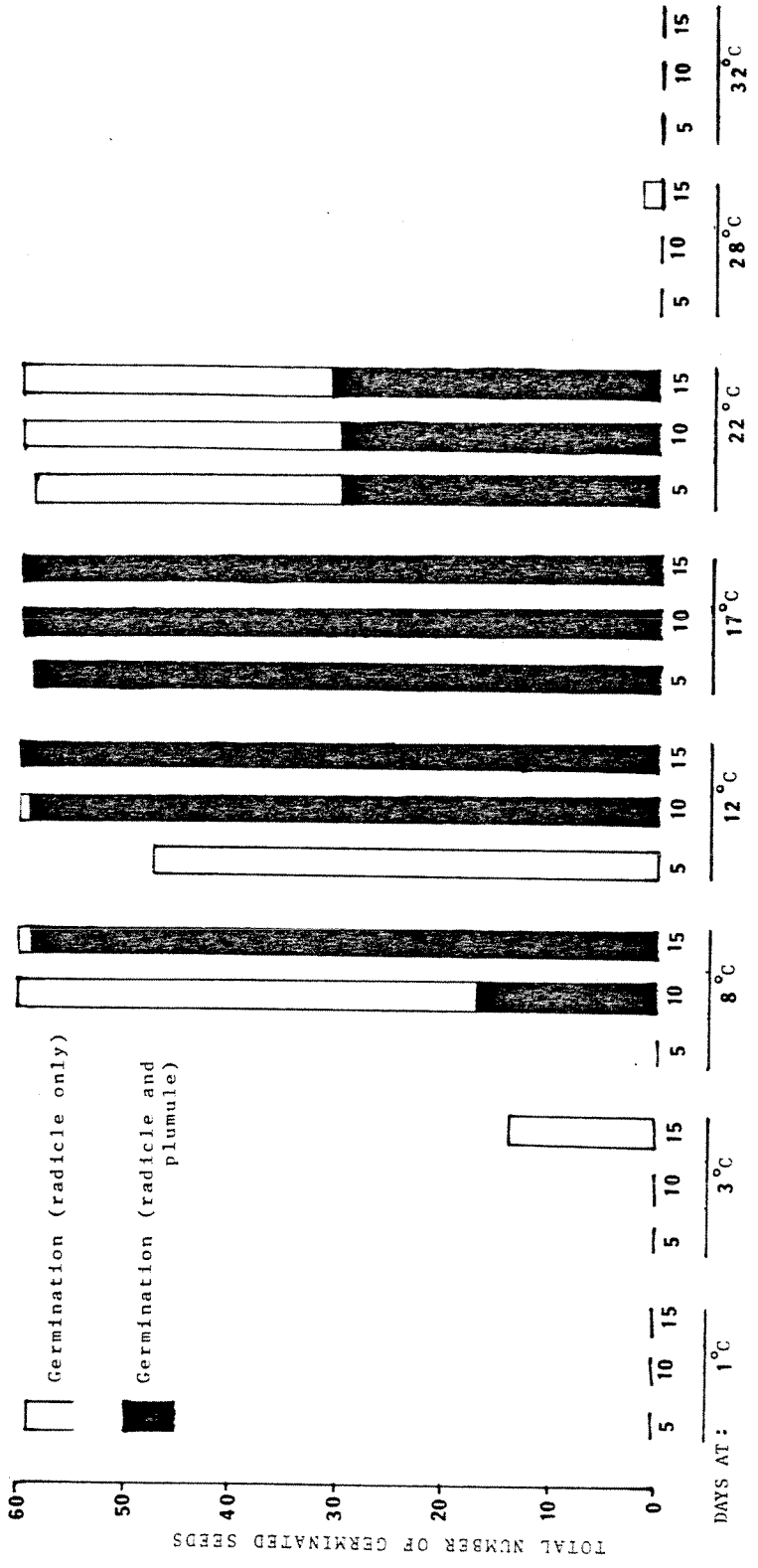


Figure 7. The influence of temperature on the germination of Bromus pectinatus Thunb..

At the lowest temperatures, 1 C and 3 C the seeds still appeared healthy after 15 days, but few seeds had germinated (Figure 7). Hulbert (1955) observed that 50% of 1 year old *B. commutatus* seeds germinated in 14.5 days at 10 C, 6.75 days at 20 C and 5.5 days at 30 C. Beal (1897) observed that *B. secalinus* germinated on, and sent roots into, cakes of ice.

The seeds used in this experiment were nearly two years old and this may have contributed to the wide range of germination temperatures. Hulbert (1955) observed with *B. brizaeformis*. *B. japonicus* and *B. tectorum* that seed sensitivity to temperature decreased with increasing age. He also observed that optimum temperature for germination of *B. tectorum* and *B. japonicus* increased with age of the seed. The optimum temperature for germination of *B. pectinatus* of 17 C may actually be a characteristic of older seeds of *B. pectinatus* and is possibly a lower value for younger seeds.

In places with a long evolutionary history of the species, distribution of members of the tribe *Festuceae*, to which the genus *Bromus* belongs is considered to be highly correlated with mid-summer temperatures (Hartley, 1973). In the highlands of Kenya, at altitudes 2000 to 3000 m, the mean range of temperatures is from 3 C to 23 C with a mean average temperature of 14 C. An optimum temperature for germination of *B. pectinatus*, a highland plant, of 17 C is therefore not unreasonable. Temperature requirements for germination, in part, regulate distribution of *B. pectinatus*.

Effect of Seed Afterripening Treatments on Germination of *Bromus pectinatus* Thunb.

Preheating at 60 C for 7 days or prechilling at 3 C for 12 days prior to germination did not break the dormancy of 4 month old hulled *B. pectinatus* seed. No germination occurred in the preheated or in the prechilled seeds, but untreated seeds had 3% germination, and 16 month old seed had 47% germination within the 7 day germination period.

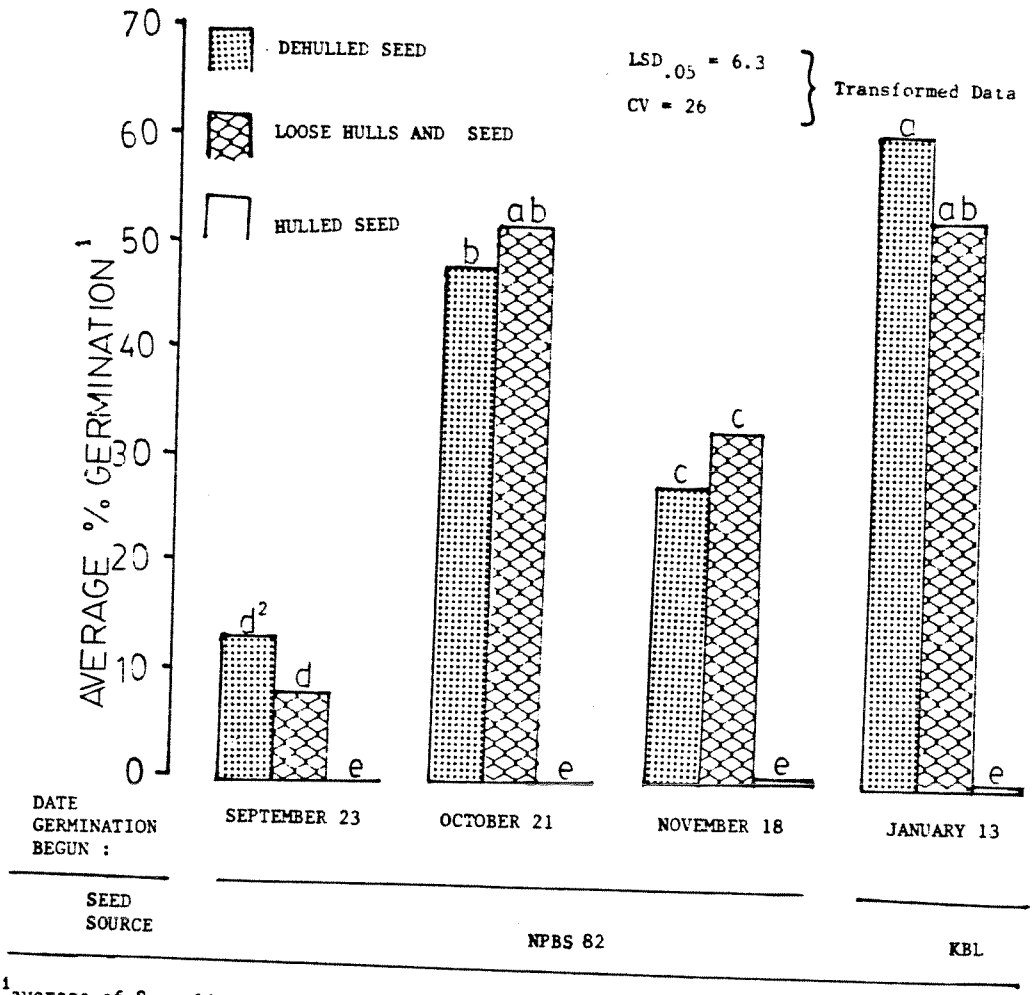
These results disagree with Thill *et al.* (1984) who observed that dry caryopsis of *B. tectorum* exposed to high temperature (50 C) had improved germination. It may be that 60 C is too high a preheating temperature for *B. pectinatus*.

The lack of any germination promotion by prechilling was not unexpected. A chilling requirement is usually a survival characteristic of species from temperate climates and *B. pectinatus* is found mainly in tropical climates, albeit at the temperate altitudes.

Influence of the Seed Hull on Germination of *Bromus pectinatus* Thunb.

Removing the lemma and palea from the caryopsis greatly increases the germination of recently harvested seeds of *B. pectinatus* (Figure 8). In this study the maximum germination was 61% for dehulled seed and 0.6% for hulled seed. Seed germination percentage varied with each trial date.

Dehulled seeds, whether loose husks was added together with the seed, or not, had similar germination percentages in each trial (Figure 8). The implication of this result was that there is not likely a strong easily leachable germination inhibitor in the lemmas and paleas



[1]average of 8 replicates, 20 seeds each

[2]Bars topped with the same letters do not differ significantly ($P \leq .05$) by the LSD test

Figure 8. The influence of the lemma and palea on the germination of Bromus pectinatus Thunb.

of *B. pectinatus*. If a chemical inhibitor was present it was either not water soluble, or required intimate contact with the caryopsis to inhibit germination. Inhibition of germination by the lemma and palea of *B. pectinatus* may be a physical effect blocking the entry of water or oxygen.

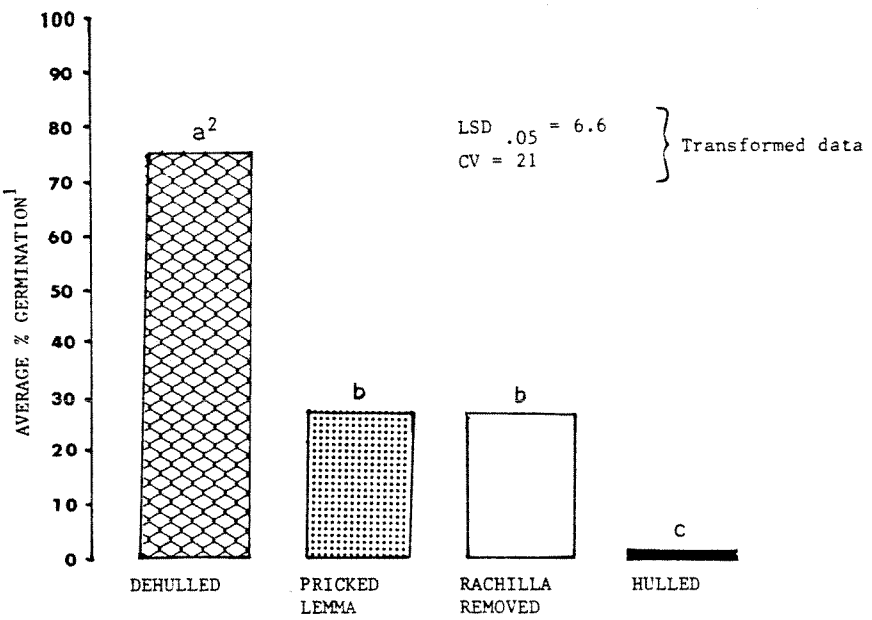
In nature soil microorganisms, and/or abrasion may gradually degrade the lemma and palea of *B. pectinatus* seed and allow the seed to germinate. This characteristic can make control of *B. pectinatus* more difficult. Seeds that require abrasion tend to break dormancy at different times rather than as a sudden flush (Harper, 1977).

Effect of Lemma Pricking and Rachilla Removal on the Germination of *Bromus pectinatus* Thunb.

Pricking the lemma, or removing the rachilla segment induced germination in *B. pectinatus*, but not as much as completely removing the lemma and palea (Figure 9). Germination was 75% for dehulled seed, 28% for pricked seed, 26% for rachilla removed seed and only 1% for hulled seed.

Part of the innate dormancy in *B. pectinatus* may be due to the physical restriction of gas or water access to the embryo by the lemma and palea. Damage (by pricking or rachilla removal) and complete removal of the lemma and palea all increased germination. If dormancy was purely due to a chemical inhibitor pricking would be unlikely to have an influence on germination.

If the dormancy was due to a physical effect then the effectiveness of pricking the lemma or removing the rachilla segment on the germination of *B. pectinatus* would be dependent, in part, on how



[1]average of 8 replicates , 20 seeds each

[2]Bars topped with the same letter do not differ significantly ($P < .05$) by the LSD test.

Figure 9 . The influence of pricking the seed coat and removing the rachilla segment on the germination of Bromus pectinatus Thunb. .

extensive an opening was created and where it was located. These factors may explain why the germination of the pricked and rachilla removed seed germinated less than when the lemma and palea were completely removed.

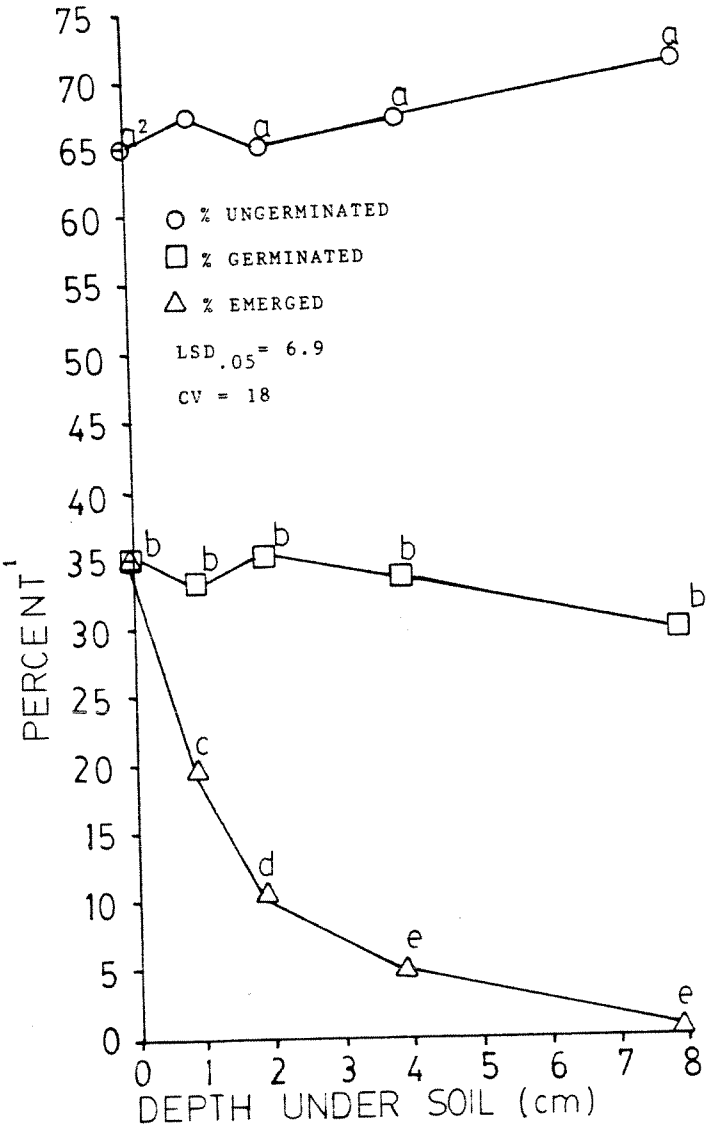
Effect of Seeding Depth on Germination and Emergence of *Bromus pectinatus* Thunb.

Germination of *B. pectinatus* was unaffected by depth in the soil (Figure 10). At depths from 0 to 8 cm the average germination was 33%. Maximum emergence (35%) occurred when the seed was placed on the soil surface. However, in this study continuous high humidity was maintained and such high air humidity would not occur continuously under natural conditions where soil surface drying occurs.

On average, emergence was 19, 11, 4 and 0% from depths of 1, 2, 4 and 8 cm, respectively. These results are in agreement with Aldrich (1984) who stated that it was generally observed that there was an inverse relationship between seed depth in the soil and emergence, while germination was relatively unaffected by depth of burial.

Similar studies have been conducted on other *Bromus* species. With *B. tectorum*, in a moist loam soil, Hulbert (1955) observed that seedling emergence was greater at a 2 cm planting depth (100%) than at a 4 (93%) or 6 cm (14%) depth. McNeil and Peeper (1977) grew *B. secalinus* in a loamy sand soil and had 35% emergence of surface sown seed, 92% emergence of seed at a depth of 2.5 cm, 74% at 5 cm, 1% at 10 cm and no seedlings emerged from the 15 and 20 cm depth.

B. pectinatus has an elongating first internode and coleoptile method of seedling emergence. In the petri dishes the coleoptile tip



[1]average of 4 replicates, 60 seeds each

[2]Graph points followed by the same letters do not differ significantly ($P < .05$) by the LSD test.

Figure 10. The influence of seed depth under a clay loam soil on the germination and emergence of Bromus pectinatus Thunb. .

has been observed to extend as far as 7.7 cm from the embryo. However, on average the coleoptile tip is 3 to 4 cm from the embryo. Based on these coleoptile lengths it would be expected that under the more rigorous conditions of soil germination that no seedlings would emerge from the 8 cm depth.

CHAPTER 4

Field Emergence and Dormancy of *Bromus pectinatus* Thunb.

ABSTRACT

Investigations were conducted on the field emergence pattern, and after-harvest laboratory germination of *Bromus pectinatus* Thunb. At Njoro, Kenya, in 1983, a relationship between precipitation and emergence of *B. pectinatus* was observed. There was a large initial flush of *B. pectinatus* in May, after the onset of the long rains, which was followed with a second, smaller, flush with the onset of the second half of the long rains in July. There was no emergence of *B. pectinatus* during the dry season. The lack of emergence during the dry season is suggested to be due to seed dormancy present in the caryopsis and induced by the lemma and palea. In seeds where the lemma and palea were removed partial germination occurred immediately after harvest, and the percentage germination gradually increased as storage time increased. In seeds where the lemma and palea were left on germination did not occur until after 9 months in storage. After 10 months in storage the presence of the lemma and palea on the seed had no influence on *B. pectinatus* seed germination.

INTRODUCTION

The National Plant Breeding Station (NPBS) Njoro, Kenya, where the following investigations were carried out, has a semi-humid climate with two main seasons. The wet season from March to September and the dry season from October to February. The season of effective rainfall, the wet season, or the "long rains", has a bimodal pattern of rainfall with peaks in April and August. June is usually the dryest month of the wet season. There is usually little effective rainfall during the dry

season, except for the "short rains" of November.

The germination behavior of *B. pectinatus* needs to be synchronized with the seasons to provide a maximum chance for survival. *B. pectinatus* seedlings which emerge during the dry season would not receive enough moisture for growth to maturity. There would need to be some dormancy mechanism which would restrict *B. pectinatus* from germinating during the dry season but would allow adequate germination of *B. pectinatus* during the long rains after the crops have been sown.

Innate dormancy is very common in *Bromus* species. Innate dormancy, of up 5 months after harvest, has been observed in *B. mollis* and *B. rubens* (Laude, 1956), *B. secalinus* (Steinbauer and Grigsby, 1957a), *B. japonicus* (Baskin and Baskin, 1981; Hulbert, 1955), *B. tectorum* (Hulbert, 1955; Laude, 1956; Steinbauer and Grigsby, 1957a), *B. rigidus* (Hulbert 1955; Laude, 1956) and *B. brizaeformis* and *B. commutatus* (Hulbert, 1955).

Roberts and Potter (1980) observed in several weed species that once the spring flush occurred, seedling emergence was primarily influenced by the pattern of rainfall. Should *B. pectinatus* germinate completely with the onset of the long rains, or germinate in several flushes with defined peaks, control through management techniques would be possible.

This paper reports the results of observations on the field emergence pattern, in relation to rainfall, of *B. pectinatus* and relates this emergence pattern with the after harvest laboratory germination of *B. pectinatus* kept in storage.

MATERIALS AND METHODS

After-Harvest Germination of *Bromus pectinatus* Thunb.

Spikelets were hand stripped from mature panicles of *B. pectinatus* on September 16, 1982, at the NPBS, Njoro. The spikelets were air dried, placed in an air tight glass jar, and stored in an office drawer.

At 28 day intervals, beginning September 23, 1982, and ending January 19, 1984, seeds were removed from the jar and germinated in petri dishes, in the uncontrolled physical environment of an office drawer. Each petri dish was 9 cm in diameter and contained 2 sheets of Whatman Number 1 filter paper moistened with 5 ml of distilled water. Twenty dehulled, or hulled, seeds were placed uniformly into each petri dish. Dehulled seeds had the lemma and palea carefully peeled of the seed exposing the caryopsis. Hulled seed was the unmodified seed.

Every 7 days throughout the germination trial, the seeds were counted and removed from the petri dishes. Occasionally, as required, 1 to 2 ml of distilled water was added to the filter paper to maintain adequate moisture for continued germination. After a germination interval of 28 days the trial was discontinued and the next trial was initiated.

Petri dishes were arranged within the drawer in a completely randomized design with 8 replicates. Data was analysed using the least significant difference test at the 1% significance level following analysis of variance. Only those differences found significant by this test were considered meaningful.

Field Emergence Pattern of *Bromus pectinatus* Thunb.

Five 1 m^2 quadrats, were positioned at random in a *B. pectinatus* infested field at NPBS, Njoro. The field was previously in maize and was disc ploughed and tandem disc harrowed in early January before the quadrats were marked out.

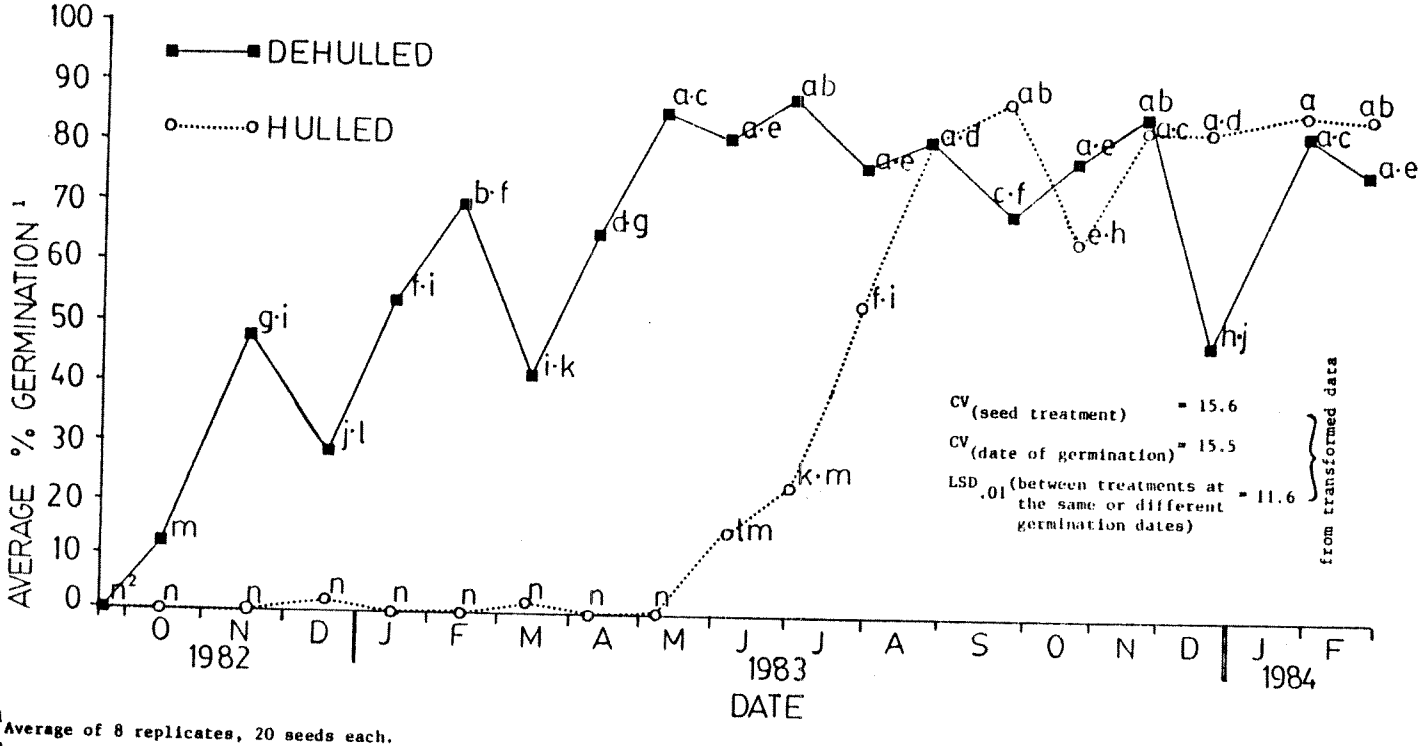
The quadrats were sprayed with paraquat at a 1 kg/ha rate at the start of the experiment (January 17, 1983) and throughout the year after each quadrat inspection. During the inspections, which occurred every 4 to 5 weeks, the number of emerged *B. pectinatus* plants were counted. Application of paraquat after each inspection killed all emerged plants in the quadrat area.

Meteorological information was collected near this site during the study period. The precipitation and temperature records were plotted along side the emergence record to determine if there is a relationship between emergence and climatic conditions.

RESULTS AND DISCUSSION

After-Harvest Germination of *Bromus pectinatus* Thunb.

The hull of a *B. pectinatus* seed is important in inhibiting germination through physical and/or chemical means. Dehulled seeds of *B. pectinatus* germinated immediately after harvest, whereas hulled seed did not germinate until after 9 months of storage (Figure 11). The caryopsis itself also contributed to the germination inhibition. In dehulled seed there was only partial germination immediately after



[1] Average of 8 replicates, 20 seeds each.

[2] Points on the graph followed by the same letters do not differ significantly ($P < .01$) by the least significant difference test on the arc sin $\sqrt{X}$ transformed data.

Figure 11. After harvest germination of hulled and dehulled Bromus pectinatus Thunb. stored under laboratory conditions.

harvest (13%), but this percentage germination gradually increased over the following 7 months.

The reduced germination of freshly harvested seed is most likely due to innate dormancy induced primarily by the lemma and palea and partially by some factor in the caryopsis itself. The innate dormancy is not likely due to incomplete seed development. Incomplete development has been found to be unimportant in the viability of other *Bromus* species. Hulbert (1955) with *B. tectorum* and Gill (1938) with *B. mollis*, observed that early collected seeds (green) of these plants had high viability.

The reduced germination of freshly harvested seed may be an enforced dormancy, due to unfavorable temperatures for germination. Over the course of the experiment the office drawer temperature fluctuated between 18 and 21 C and this temperature range may have been too high for germination of freshly harvested *B. pectinatus* seeds. It has been observed in *B. tectorum* and in *B. secalinus* that temperatures 15 C, and less, were best for germination of freshly harvested seeds, while more mature seed would germinate at higher temperatures (Hulbert, 1955; Steinbauer and Grigsby, 1957b).

Regardless of whether the seeds were hulled or dehulled, germination after 18 months in storage was at least 77 per cent (Figure 11). *B. pectinatus* can remain viable in dry storage for at least 18 months. Steinbauer and Grigsby (1957a) found that seeds of *B. secalinus* germinated 91% after 8 years of dry storage in sealed containers. Hulbert (1955) found florets of *B. tectorum* stored for 11.5 years in a paper sack in a laboratory were still viable (96%).

In nature, soil microorganisms, leaching and cultivations may

remove the hull and any inhibitors from the seed. The pattern of germination of the dehulled seed may be more representative, than that of hulled seed, of what would occur in the field. The germination pattern of hulled seed is important in that it represents the maximum innate dormancy interval in *B. pectinatus* under the conditions of this experiment.

Field Emergence Pattern of *Bromus pectinatus* Thunb.

Soil moisture had an overriding influence on *B. pectinatus* seedling emergence. At Njoro, in 1983, *B. pectinatus* did not emerge until after the onset of the "long rains" in April (Figure 12). This large initial flush ended in June (low precipitation) and a second smaller flush started with the onset of the second part of the long rains in July. The second flush was smaller than the first and the seedling emergence gradually declined with time even though precipitation was adequate. The reduction in the number of plants which emerged, and gradual decline of emergence, in the second flush may be explained as either depletion of the seed bank or induction of a secondary dormancy into some seeds by the June drought. The second flush ended in September and *B. pectinatus* seedlings did not emerge during the last two months of 1983.

The observed relationship between emergence of *B. pectinatus* and precipitation is in agreement with the observation of Jain (1982) for other *Bromus* species. He observed that dormancy in *B. mollis*, *B. rigidus* and *B. rubens* was highly correlated with the rainfall pattern at their collection sites. He also observed that in *B. mollis* there was a direct relation between the amount of dormancy and the probability of a

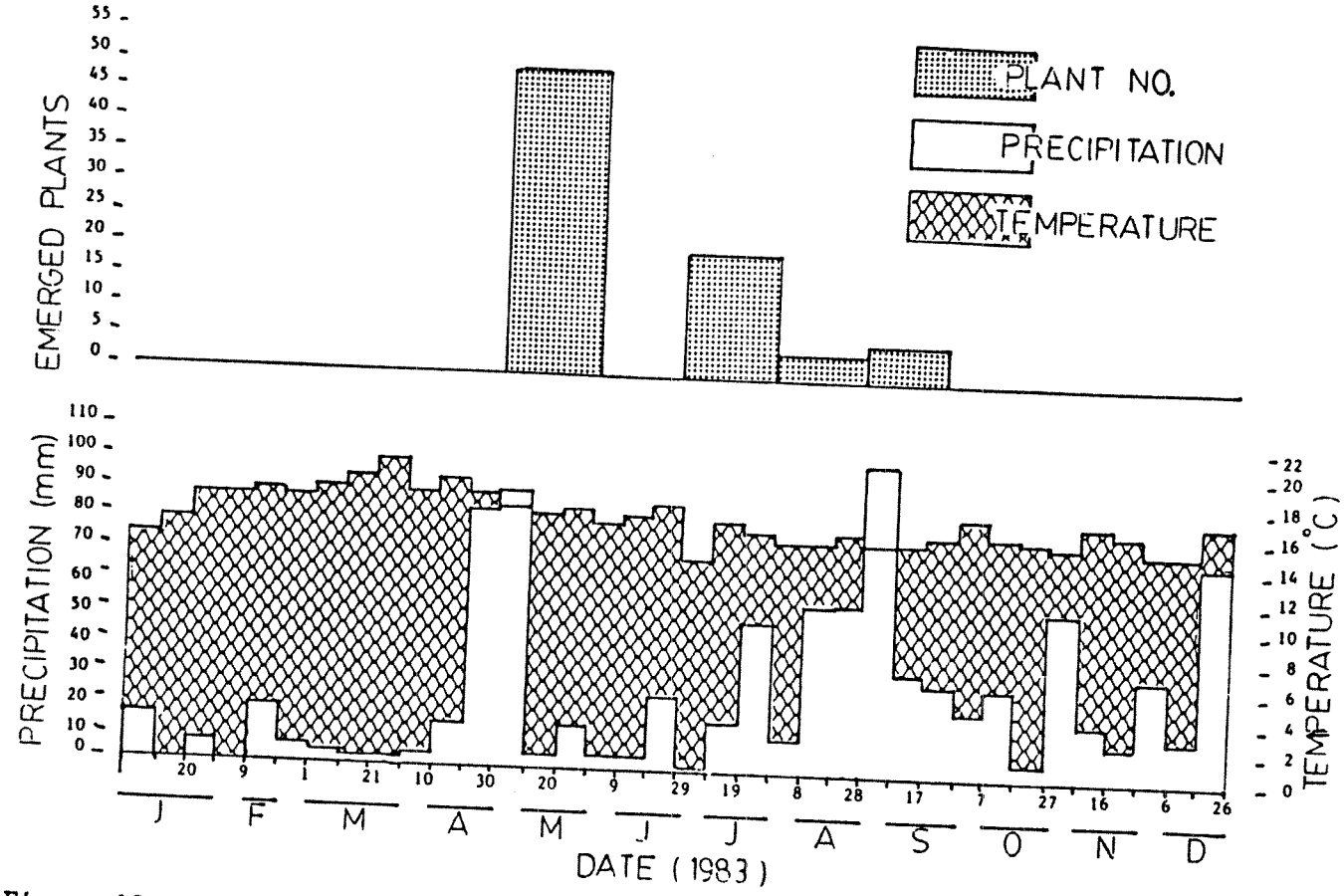


Figure 12. Field emergence pattern of Bromus pectinatus Thunb. at the NPBS, Njoro, and relation to 10 day average precipitation and temperatures during 1983.

summer rainfall.

There was no relationship between temperature and the emergence of *B. pectinatus* (Figure 12). *B. pectinatus* is a plant of tropical origin (Clayton, 1971) and would therefore would not evolve a seasonal emergence pattern based on the relatively small tropical seasonal fluctuations. At Njoro, daily temperature fluctuations were much greater than the seasonal fluctuations. It has been demonstrated that the distribution of native *Bromus* species is often determined mainly by temperature (Hartley, 1973; Tieszen *et al.*, 1979).

Due to the distinct seasonality of precipitation in Kenya it would be to the survival advantage of *B. pectinatus* to time emergence to occur when there is adequate moisture for growth through to maturity. These studies indicate that seed dormancy is responsible for timing emergence in *B. pectinatus*.

Hulled seeds did not germinate until May (Figure 11) and field emergence did not begin until May (Figure 12). Dormancy is likely to be responsible for the lack of germination of hulled seed. It is also likely that seed dormancy was also responsible for inhibiting emergence, through the dry season, in the field. It is also possible that conditions during the dry season were just too dry, and/or the soil temperature just too hot, for emergence of *B. pectinatus*.

Scarification may be important in germination of *B. pectinatus*. Dehulled seeds began germinating sooner after harvest than did hulled seeds (Figure 11). Seedlings of *B. pectinatus* emerged continuously through the long rains, in at least two flushes. Harper (1977) states that seeds that require abrasion do not have only a sudden flush but break dormancy at different times.

The emergence of *B. pectinatus* throughout the growing season, not as one flush, may have been the result of a heterogeneously mature seed source. Once *B. pectinatus* reaches the reproductive phase panicles emerge successively over the plants remaining life. Early emerged plants are shedding seed while other plants and panicles are being initiated. Seed will readily disarticulate from mature spikelets except for the basil seed in each spikelet, which often remain attached. *B. pectinatus* is shedding seed continuously from the time the first panicle on the earliest plant matures, till the plants are killed by cultivation or dessication. The seedbank of *B. pectinatus* will therefore be of heterogeneous maturity and even with a uniform innate dormancy interval *B. pectinatus* seed would emerge throughout the growing season.

B. pectinatus seeds may persist in the seed bank for longer than a year. In the germination study only seeds which appeared well developed were germinated and yet the maximum germination within the 18 month germination period was only 88% (Figure 11). The lack of complete germination implies that there is an innate dormancy in some seeds which persists longer than the 18 months of the germination study. So even though in Figure 12 it appears that most seeds germinated and emerged within the first year after release, some seeds (as much as 12%) may persist in the soil for a longer period.

The occurrence of a large initial flush of *B. pectinatus* is useful towards its control. Application of selective herbicides after this flush, say in June, would effectively reduce the *B. pectinatus* population in a field. Nonetheless, the existence of continuous germination through the wet season, and the possibility of some seed persisting for more than a year, means that control of *B. pectinatus* will be a long term process, involving careful considered management.

CHAPTER 5

Bromus pectinatus Thunb. Interference in Crops

ABSTRACT

Interference studies were conducted, at various sites in Kenya, with the weed *Bromus pectinatus* Thunb. in wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and rapeseed (*Brassica napus*). Field studies determined that the yield of wheat (cv. Tembo) would be reduced 50% with an infestation of 11 *B. pectinatus* plants/m^2. When sowing of wheat (cv. Kenya Paa) or barley (cv. Tumaini) was delayed, after final seedbed preparation, yield reductions were correlated with the length of delay. The yield of the wheat was less affected by the delayed sowing than was the yield of the barley. A replacement series experiment with varying proportions of wheat (cv. Kenya Kongoni) and *B. pectinatus* indicated annidation in the mixtures. The replacement series mixtures induced changes in wheat plant height, culm number and 1000 Kernal weight and in *B. pectinatus* vegetative dry matter weight. A replacement series experiment with varying proportions of rapeseed (cv. Regent) and *B. pectinatus* found that rapeseed was unaffected by the *B. pectinatus* interference. The replacement series, induced changes in rapeseed dry matter weight and *B. pectinatus* culm number and vegetative dry matter weight. A spatial interference study showed that the major interference by *B. pectinatus* on wheat (cv. Kongoni) occurs above ground.

INTRODUCTION

Bromus pectinatus Thunb. has recently become a major weed of wheat and barley in Kenya. Up until 1967 *B. pectinatus* was not considered a major weed of Kenya wheat. Bogdan (1965) did not list it as one of the weed seeds in his 1963 wheat crop samples. Ivans (1967) described *B. pectinatus* as one of the common grass weeds in East Africa. However, he did not describe it further in his book. By 1977 agronomists at Kenya Breweries Ltd. were searching for methods to control *B. pectinatus* in barley (Owino and Little, 1979). The weediness of *B. pectinatus* has come about as a result of the successful control of other weeds (Mulamula, 1983). It is not unusual for a resistant species from a ruderal site to fill niches once occupied by better adapted agrestal species now controlled by herbicides (Gluaninger and Holzner, 1982).

Little is known about the losses and the nature of the losses caused by *B. pectinatus*. The experiments presented in this paper assist in determining the extent of the losses caused by *B. pectinatus*. A field study assessed the yield losses which occurred in wheat at different *B. pectinatus* infestations. Yield loss caused by delayed sowing into a *B. pectinatus* infested site, after final seedbed preparation, was studied using wheat and barley in a delayed sowing experiment. Replacement series experiments were conducted to evaluate the effects of interference between wheat, or rapeseed, and *B. pectinatus* on yield components of each plant. A spatial interference study was conducted to determined the spatial distribution of interference between wheat and *B. pectinatus*. Based on the understanding of *B. pectinatus* interference derived from these studies

management techniques for preventing or minimizing losses have been suggested.

MATERIALS AND METHODS

Effect of *Bromus pectinatus* Thunb. Infestation On Wheat Yields

A *B. pectinatus* infested site was selected at Muthera farm, near Mau Narok. On August 17, 1983, this site was sown to wheat (cv. Tembo) with a double disc research drill to a depth of 3 cm in 17 cm spaced rows. The seed was copper dressed and sown at a 100 kg/ha rate along with 100 kg/ha of diammonium phosphate fertilizer (18:46:0). Soon after crop emergence, twenty, 1 m^2 quadrats were marked out in the field. By assessment time only 9 quadrats were suitable for evaluation. These quadrats had uniform crop stand and were free of weeds other than *B. pectinatus*. The design was similar to an additive scheme interference experiment.

On January 12, 1984, the number of *B. pectinatus* plants in the quadrats were recorded. On February 8, the wheat from the quadrats was harvested, then threshed, and the grain weighed. Regression analysis was performed on the results to determine if there was a correlation between *B. pectinatus* infestation and yields.

Effect of Delayed Sowing of Wheat and Barley, Following Final Seedbed Preparation, Into a *Bromus pectinatus* Thunb. Infested Site

This experiment was conducted at the Kenya Breweries Ltd. research station, near Mau Narok. The plot layout was 6x6 latin square design in

which each block was sown one-half to wheat (cv. Kenya Paa) and the other half to barley (cv. Tumaini). The plots were 6 m long and consisted of eight 17 cm spaced rows of wheat sown adjacent to eight 17 cm spaced rows of barley. The treatments consisted of sowing a plot at 3, 6, 9, 13, 16 and 19 days after the final site harrowing on July 21, 1982. There was no control plot.

The wheat and barley seeds were sown 2.5 cm deep with a double disc research drill. The seeds were copper dressed and sown at a 110 kg rate along with 90 kg/ha of diammonium phosphate fertilizer.

Broadleaf weeds were controlled by applying Maytril (6.8% bromoxynil, 0.8% ioxynil, 32.8% CMPP) at a 2.5 l/ha rate on September 14, 1982. *B. pectinatus* was the dominant weed through the growing season. Late into the growing season, wild oats (*Avena fatua*), ryegrass (*Lolium* sp.) and *Eragrostis* sp. emerged.

Analysis of variance was conducted on the results and the least significant difference test used to detect differences between treatments. Only those treatments which differed at the 5% level were considered meaningful. Linear regression analysis was performed on the results to detect if there was a correlation between seeding dates and yields.

Crop-weed Interference Effects in Replacement Series

A) Effect of various proportions of wheat and *Bromus pectinatus* Thunb.

The experiment was conducted in a field at the National Plant Breeding Station, Njoro. The experiment consisted of 5 treatments, in 3 replicates, arranged in a randomized complete block design. Plants were

arranged, within a 0.6 m x 1.0 m plot, in a honeycomb design with 9 cm between plants. The treatments consisted of varied proportions of wheat and *B. pectinatus* at a constant stand density. The stand proportions were 100% *B. pectinatus*, 75% *B. pectinatus* and 25% wheat, 50% *B. pectinatus* and 50% wheat, 25% *B. pectinatus* and 75% wheat, and 100% wheat. Plants were arranged for each treatment as shown in Figure 13.

Each plot was initially marked out with a naiboard template. On July 22, 1983, into each wheat position, two seeds of copper treated wheat (cv. Kongoni) were sown at a depth of 2 cm. Wheat plants were thinned to one plant per position immediately after emergence.

On July 24, 1983, early 1-leaf stage *B. pectinatus* plants were carefully transplanted into the *B. pectinatus* positions in each plot. The *B. pectinatus* transplants were obtained from flats into which dehulled seeds from Njoro were sown.

On August 5, 1983, the experiment was sprayed with Brominal M (bromoxynil 23%, MCPA 23%) to control broad leaved weeds, and with thiodine to control cut worms. On September 5, 1983, the experiment was sprayed with Tilt (propiconaziole 250 g/l) to prevent infection of the wheat and the *B. pectinatus* by rust (*Puccinia* sp.). The blocks were watered by irrigation when precipitation was not adequate. No fertilizer was added.

The center 20 plants of each plot, as shown in Figure 13, were harvested on December 3, 1983 after the wheat matured. At harvest, plant heights and culm numbers were recorded. The plants were stored in a drying room for a week, and then the vegetative dry matter weight was determined. Vegetative dry matter was determined, instead of whole

plant dry matter, because *B. pectinatus* had begun to shed seeds before harvest. In wheat, the grain yield and seed numbers, were also determined. Thousand kernel weight, for each wheat plant, was then determined using the equation:

$$1000\ (\textit{Grain yield}\ (g)/\textit{Grain number})$$

Results were analysed by analysis of variance and the least significant difference test was used to indicate differences between treatments. Only differences at the 5% level were considered meaningful.

The vegetative dry matter yields were used to determine the relative yields (RY) and the relative yield totals (RYT) for each treatment. The relative yield of *X* was calculated as the yield of *X* in mixture (per plot)/yield of *X* in pure stand (per plot), where *X* can be either the vegetative dry matter of wheat or *B. pectinatus*. Relative yield total is the sum of the relative yield of each plant in mixture.

B) Effect of various proportions of rapeseed and *Bromus pectinatus* Thunb.

The experiment was conducted in a field at the National Plant Breeding Station, Njoro, using the same basic design and techniques as were used in A, described above. However, in this experiment rapeseed (cv. Regent) was used in place of wheat.

On September 27, 1983 both cotyledon stage rapeseed and early one-leaf stage *B. pectinatus* were carefully transplanted from flats into the appropriate plant positions as illustrated in Figure 13. The plots

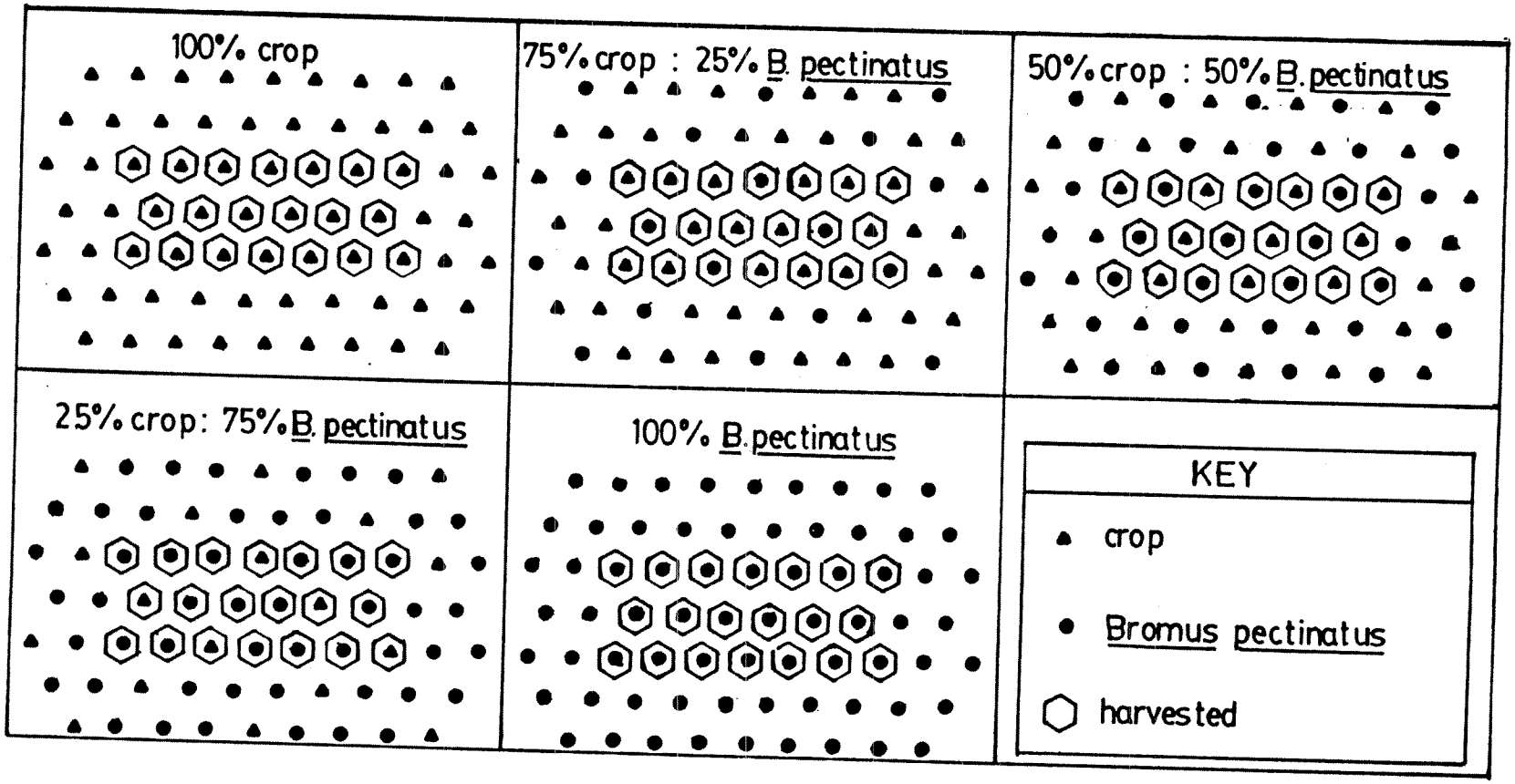


Figure 13. Diagram showing plant arrangement at each of the mixtures used in the replacement series experiments.

were hand weeded, and watered throughout their growth as required. No fertilizer was used.

The center 20 plants of each plot, as shown in Figure 13, were harvested on March 12, 1983, when the rapeseed was mature. At harvest plant height, culm number, and vegetative dry matter weight was determined for each *B. pectinatus* plant. In rapeseed the total dry matter weight of each plot was determined (including seed pods).

Dry matter yields were used to determine RY. The *X* value is either the vegetative dry matter of *B. pectinatus* or the whole plant dry matter of rapeseed.

Spatial effects of interference between wheat and *Bromus pectinatus* Thunb.

Interference boxes were constructed to study the interference between *B. pectinatus* and wheat (Figure 14). There were 5 major soil compartments, each 40 cm long by 15 cm deep by 15 cm wide. Two of these compartments were further subdivided into two sections 7 cm wide. Each aerial portion of the competition box was similar in size to the soil compartments and could be stacked to separate the treatments and to study competition for light. When wheat plants reached a height of 15 cm a second aerial portion was connected. This additional aerial portion separated the plants until the boot stage. The aerial boxes were painted a flat white to reflect diffuse light into the chambers.

Seeds of wheat (cv. Kongoni) and *B. pectinatus* were sown 1 cm deep into rows, centered in each compartment "half-section", on February 21, 1983, into Njoro clay loam soil (pH 5.7). Boxes were placed in a shadehouse and watered as required. Both species were thinned to twelve

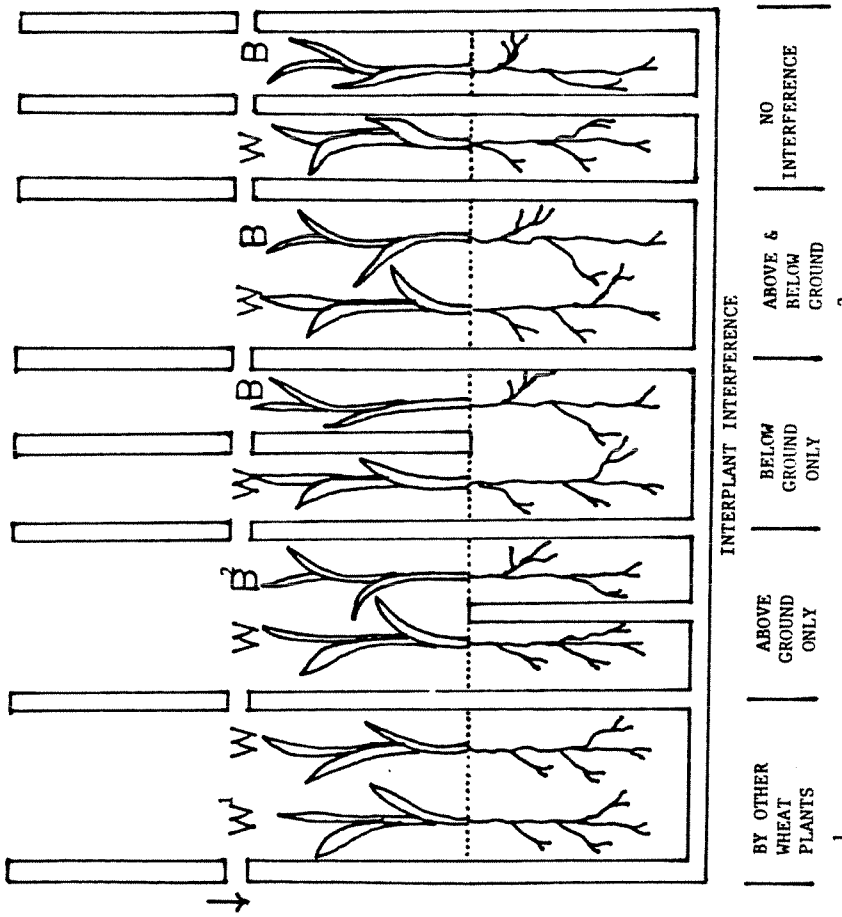


Figure 14. Diagram of interference boxes with aerial portions above and soil compartments below (Not to scale).

plants per row on March 7, 1982, when the wheat was in the 2-leaf stage and the *B. pectinatus* was in a 1-leaf stage.

There was some random damage to the wheat heads by rats in mid-April and by birds in late May. *B. pectinatus* was not damaged.

On June 5 plant heights were recorded as the plants were harvested by clipping at ground level. The plants were then air dried and individual dry matter weights, culm numbers, and head or panicle numbers for each plant were determined.

There were four replicates of each treatment arranged in a randomized complete block design. The results were analysed by analysis of variance and the least significant difference test was conducted on the data. Only those differences detected by the least significant difference test at 5% were considered meaningful.

RESULTS AND DISCUSSION

Effect of *Bromus pectinatus* Thunb. Infestation On Wheat Yields

Infestations of *B. pectinatus* significantly reduced wheat yields. There was a strong negative correlation between the number of *B. pectinatus* plants/m^2 and wheat yields (Figure 15). Although a sigmoidal curve is usually used to represent the effect of weed number on crop yield it was found that a linear equation, on the transformed data, similar to that used by Dew (1972) with wild oats (*Avena fatua*), most accurately presented this data.

Using the equation, a 50% reduction in wheat yield occurred at a *B. pectinatus* infestation of 11 plants/m^2. The large wheat yield

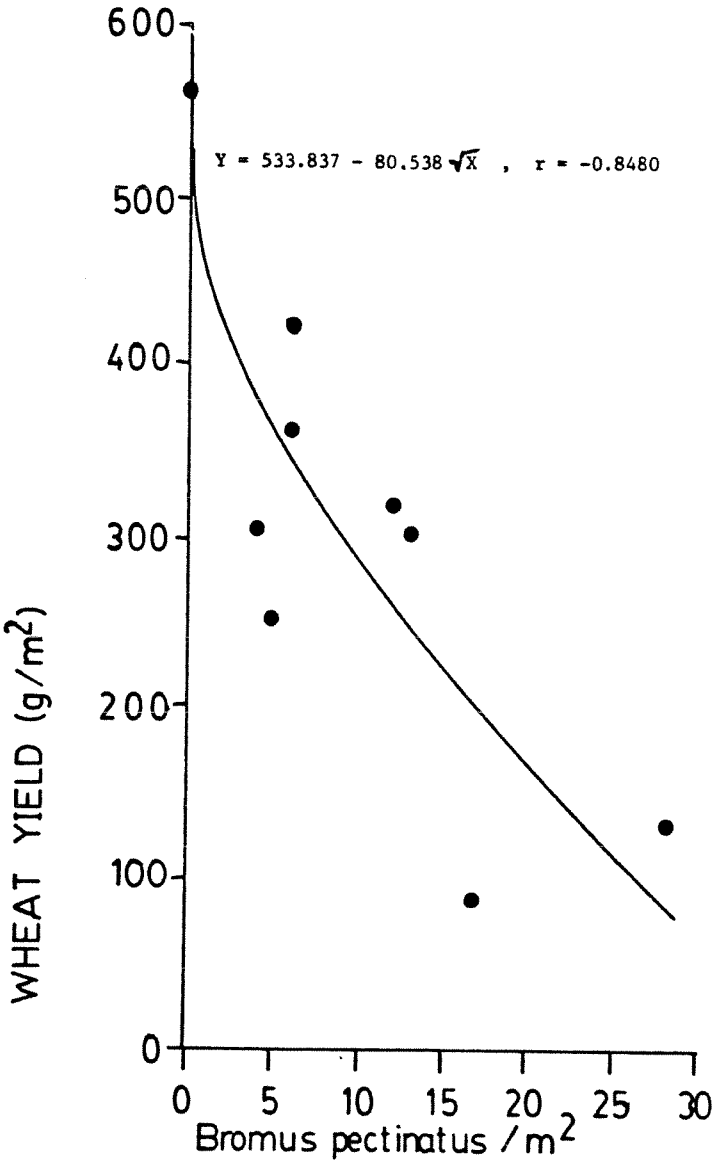


Figure 15. Field measurements of the influence of Bromus pectinatus Thunb. infestation density on wheat yields.

reduction, with so few *B. pectinatus* plants, implies that *B. pectinatus* is extremely competitive. However, this equation is based on a small number of samples in one field and should not be taken as a representative equation.

B. pectinatus may have been abnormally competitive in this study. Harvest losses are very dependent on cultivar, community structure, climate, soil and soil treatments, and timing of management practices. Although standard agricultural practices were conducted in this study, because of rain and machinery problems, the study was sown later than most fields in this area. In addition, *B. pectinatus* plant counts were made relatively late in the growing season and may not completely reflect *B. pectinatus* infestation in the growing season. In a field at Njoro in 1983, a pure strand of *B. pectinatus* has been observed to change in plant stand from 112 plants/m^2 in May, to 94 plants/m^2 in June, to 68 plants/m^2 in July, and finally to 28 plants/m^2 in August.

Effect Of Delayed Sowing of Wheat and Barley, Following Final Seedbed Preparation, Into a *Bromus pectinatus* Thunb. Infested Site

Delaying sowing of wheat and barley, following seedbed preparation, into a *B. pectinatus* infested field can increase crop yield losses. In wheat (Kenya Paa) and barley (Tumaini) sown at Mau Narok, there was a negative correlation between yields and relative sowing date (Table 7). The negative correlation was observed for both dry matter and grain yields.

The yield reductions in wheat and barley can be attributed to increasing weed-crop interference by delayed sowing into the *B. pectinatus* infested field. At this site *B. pectinatus* was the dominant

weed present in the crop. Broadleaved weeds were controlled with herbicide, and grassy weeds, other than *B. pectinatus* were absent till late in the growing season. Nineteen days after seedbed preparation (D.A.S.P.) the average *B. pectinatus* seedling density, in this field, was 43 plants/m^2. Of these plants 10% were in the coleoptile stage, 44% were in the one-leaf stage, and the remainder were in the two-leaf stage.

The crops developed in environments which differed over a time span of 16 days and this may be responsible for part of the yield differences due to delayed sowing. It is unlikely that a difference in environment was the major factor creating the observed yield differences. The weather, in 1982, was unusually uniform over most of the growing season.

In wheat, grain yield was affected by delayed sowing in a shorter interval than it took to reduce dry matter yield (Table 7). Grain yield of wheat plots sown 13 D.A.S.P. was lower than plots sown 3 D.A.S.P., whereas, dry matter was lower only in wheat plots sown 19 D.A.S.P.. In barley, plots sown 16 D.A.S.P. had lower dry matter and grain yields than plots sown 3 D.A.S.P..

Dry matter yields were less influenced by delayed sowing than were grain yields (Table 7). Delaying sowing of plots for 19 D.A.S.P. reduced grain yields of wheat and barley to 62% and 52%, respectively, of the grain yield of plots sown 3 D.A.S.P. In plots sown 19 D.A.S.P. wheat and barley dry matter yields were 83% and 76%, respectively, of plots sown 3 D.A.S.P.

Dry matter and grain yields of wheat were relatively less affected by increasing *B. pectinatus* competition, because of delayed sowing, than was barley (Table 7). Generally barley is considered to be more

Table 7. The influence of delayed sowing, into a Bromus pectinatus Thunb. infested site, on wheat and barley dry matter and grain production.[1]

D.A.S.P.[2] when crop sown	WHEAT		BARLEY	
	Dry Matter (Kg/m^2)	Grain Yield (g/m^2)	Dry Matter (Kg/m^2)	Grain Yield (g/m^2)
3	1.31 ab[3]	387.8 ab	0.86	148.3 a
6	1.41 a	401.3 a	0.81	120.3 ab
9	1.25 ab	354.2 abc	0.79	120.1 ab
13	1.31 ab	295.7 bcd	0.78	104.4 ab
16	1.24 b	277.8 cd	0.66	84.1 b
19	1.06 c	253.6 d	0.66	78.6 b
Average	1.26	328.4	0.76	109.3
$LSD_{.05}$	0.17	98.4	0.	48.5
C.V.	11	25	21	37
r (linear)	-0.7680*	-0.9688*	-0.9452*	-0.9740*

[1] average of 6 replicates

[2] D.A.S.P. = days after seedbed preparation

[3] numbers in the same column followed by the same letter do not differ differ significantly (P .05) according to the LSD test

competitive than wheat (Dew, 1974; Pavlychenko and Harrington, 1934). However, varieties of a crop that form a dense canopy of leaves early in the season have fewer problems with weeds than varieties that do not shade the ground (Sweet, 1976). Under these experimental conditions the wheat had more vigorous growth, was taller, and had wider leaves than did barley. The wheat also had a shorter proportion of its life under competition by *B. pectinatus* than the barley. The barley and the *B. pectinatus* were both mature by mid-December while the wheat was not mature until a month later.

In Kenya, farmers often wait until the onset of the long rains before sowing their fields to wheat or barley. The rain provides the moisture necessary for crop germination but can also delay sowing of the crop into the prepared seedbed. Delaying crop sowing allows *B. pectinatus* to germinate and start growth in absence of crop competition. The competitive advantage *B. pectinatus* gains is reflected in the reduced crop yield, proportional to the length of delay.

Crop-Weed Interference Effects In Replacement Series

A) Effect of various proportions of wheat and *Bromus pectinatus* Thunb.

On an average per plant basis, varying the relative proportions of wheat and *B. pectinatus* in a replacement series experiment, affected plant heights, culm number, and 1000 Kernal weights in wheat, and vegetative dry matter in *B. pectinatus* (Table 8). However, these effects are specific to a particular ratio and caution is advised in assigning significance to the effects. A 75/25 ratio of wheat/*B. pectinatus* caused a reduction of 1000 Kernal weight of wheat, relative

Table 8. Replacement series effects on wheat and *Bromus pectinatus* Thunb.

% Ratio of Wheat/*Bromus pectinatus*	WHEAT						*Bromus pectinatus*		
	GRAIN YIELD (g)	GRAIN NUMBER	1000 KERNAL WEIGHT (g)	VEG. DRY MATTER WEIGHT (g)	HEIGHT (cm)	CULM NUMBER	HEIGHT (cm)	CULM NUMBER	VEG. DRY MATTER WEIGHT (g)
0/100	0 b[1]	0 b	0 c	0 b	0 c	0 c	99.3 a	5.8 a	2.1 b
25/75	2.5 a	65.3 a	38.0 ab	4.8 a	73.0 b	3.7 b	99.3 a	7.0 a	3.1 a
50/50	3.0 a	79.3 a	37.3 ab	5.0 a	78.3 ab	5.1 a	102.0 a	6.3 a	2.9 ab
75/25	2.8 a	78.7 a	35.7 b	5.8 a	78.3 ab	3.3 b	104.3 a	5.6 a	3.0 ab
100/0	3.4 a	85.0 a	39.7 a	6.0 a	81.3 a	3.3 b	0 b	0 b	0 c
Average	2.3	61.7	30.1	4.3	62.2	3.1	81.0	4.9	2.2
C.V.	24	20	7	32	6	21	5	23	24
$LSD_{.05}$	1.06	23.43	3.76	2.58	7.39	1.19	8.24	2.08	0.99

[1]. Numbers in the same column followed by the same letter do not differ significantly ($P < .05$) according to the LSD test.

to the pure stand of wheat. A 50/50 ratio caused an increase in wheat culm numbers relative to the other ratios. A 25/75 ratio resulted in reduced wheat height and increased *B. pectinatus* vegetative dry matter, relative to plants grown in pure stand. *B. pectinatus* plant heights and culm numbers, and wheat vegetative dry matter, grain yield and grain number were unaffected by varying the mixture proportions.

In the experiment the stand density of the pure stand was approximately 1/3 the recommended field density. The lack of any significant reduction in grain yield or dry matter of wheat as a result of *B. pectinatus* interference may be explained by the relatively large spacing between plants. *B. pectinatus* matured about a month earlier than the wheat. This early maturity gave the wheat plants, especially in the high *B. pectinatus* proportion plots, less interference late in the growing season. The reduced interference early in the growing season may have caused reduced wheat height in the 25/75 wheat to *B. pectinatus* mixture. The reduction in one thousand kernel weight in the 75/25 mixture may also have occurred because of the increased interference early in the season. In the 25/75 mixture *B. pectinatus* may have responded to wheat interference by increasing vegetative dry matter. The increased vegetative dry matter in *B. pectinatus* was not a result of greater height, or more culms.

The RY of wheat, in mixture with *B. pectinatus*, was close to that which would be predicted (Table 10A). The RY for *B. pectinatus* in mixture was higher than might be predicted. In mixture, *B. pectinatus* made a greater relative yield contribution than did wheat. The RYT of the mixture became larger as the *B. pectinatus* became a greater proportion of the mixture.

The RYT of the mixtures were greater than 1.0. The annidation implies that there is niche differentiation by the wheat *B. pectinatus* mixtures. Annidation in mixture may be the result of *B. pectinatus* maturing earlier in pure stand than when in mixture.

B) Effect of various proportions of rapeseed and *Bromus pectinatus* Thunb.

On an average per plant basis rapeseed dry matter weight and *B. pectinatus* culm number and vegetative dry matter weight was affected by varying the relative proportions of rapeseed and *B. pectinatus* (Table 9). At a 25/75 ratio of rapeseed and *B. pectinatus* the dry matter production of rapeseed was more than twice that of the dry matter produced in any other mixture. The number of culms produced by *B. pectinatus* was reduced, relative to the pure stand, under any mixture proportion with rapeseed, and the most vegetative dry matter was produced by *B. pectinatus* in the 75/25 rapeseed/B. pectinatus ratio. *B. pectinatus* plant height was not altered by varying the mixture proportions with rapeseed.

The experimental design used had a density for the pure crop stand of approximately the same density as that recommended for field plantings of rapeseed (seed rate 4 kg/ha) in Kenya. However, the highest per plant rapeseed dry matter yields were achieved with a rapeseed stand density 1/4 that of the pure stand (*i.e.* for the 25/75 rapeseed/*B. pectinatus* mixture), even though it was the highest level of interference by *B. pectinatus* tested. Therefore, it can be inferred that *B. pectinatus* interferes very little with rapeseed. The per plant rapeseed dry matter increase at a reduced stand proportion of rapeseed

Table 9. Replacement series effects on rapeseed and *Bromus pectinatus* Thunb.

% Ratio of Rapeseed / *Bromus pectinatus*	RAPESEED DRY MATTER WEIGHT (g)	*Bromus pectinatus* HEIGHT (cm)	*Bromus pectinatus* CULM NUMBER	*Bromus pectinatus* VEG. DRY MATTER WEIGHT (g)
0/100	0 b[1]	87.3 a	4.1 a	3.4 bc
25/75	100.0 a	90.7 a	2.8 b	2.8 c
50/50	39.3 b	90.3 a	2.5 b	3.7 b
75/25	30.0 b	89.7 a	2.5 b	5.6 a
100/0	30.7 b	0 b	0 c	0 d
Average	40.0	71.6	2.4	3.09
C.V.	57	5	27	10
$LSD_{.05}$	43.0	6.48	1.23	0.59

[1] Numbers in the same column followed by the same letter do not differ significantly ($P \leq .05$) according to the LSD test.

Table 10. The relative yield and relative yield totals in a replacement series experiment of Bromus pectinatus Thunb. grown in mixture with A) wheat and B) rapeseed .

A)WHEAT

% Ratio of wheat/Bromus pectinatus	RELATIVE YIELD		RELATIVE YIELD TOTAL
	WHEAT	Bromus pectinatus	
0/100	0	1.00	1.00
25/75	0.20	1.11	1.31
50/50	0.42	0.70	1.12
75/25	0.73	0.36	1.09
100/0	1.00	0	1.00

B)RAPESEED

% Ratio of rapeseed/Bromus pectinatus	RELATIVE YIELD		RELATIVE YIELD TOTAL
	RAPESEED	Bromus pectinatus	
0/100	0	1.00	1.00
25/75	0.81	0.63	1.44
50/50	0.64	0.54	1.18
75/25	0.73	0.41	1.14
100/0	1.00	0	1.00

implies that there is a large amount of inter-rapeseed interference at recommended field densities. The recommended rapeseed seeding rates may be higher than necessary for maximum per plant dry matter production.

The broadleaves of the rapeseed plants asserted interference on *B. pectinatus* at all mixture ratios from soon after transplanting through to maturity. At maturity the rapeseed towered more than a meter above the tallest *B. pectinatus* plants. *B. pectinatus* vegetative dry matter increased when the rapeseed to *B. pectinatus* ratio was 75/25. This increased vegetative dry matter yield is not accounted for by increased height or number of culms. In fact, the number of *B. pectinatus* culms was reduced with rapeseed interference. Again, as in the wheat *B. pectinatus* replacement series experiment, the increased *B. pectinatus* vegetative dry matter with increased crop interference is likely the result of the *B. pectinatus* in mixed plots taking longer to mature than plants in pure stand or at lower rapeseed proportions. Even plants delayed in maturity by rapeseed interference, at lower rapeseed proportions, were mature a month before the rapeseed.

The RYT for the rapeseed *B. pectinatus* mixtures become larger as *B. pectinatus* becomes a greater proportion of the mixture (Table 10B). This observation implies that *B. pectinatus* makes a greater contribution to the RYT than does rapeseed. The RY of rapeseed in the 75/25 rapeseed/*B. pectinatus* mixture is about what would be predicted from the pure stand, while the RY of *B. pectinatus* in the same mixture is greater than would be predicted. The greater contribution to the RYT by *B. pectinatus* in the 75/25 mixture may be explained by its delayed maturity under rapeseed interference. However, at lower proportions of rapeseed

the RY of *B. pectinatus* is not significantly higher than might be predicted from the pure stand. In addition, in the 25/75 mixture the RY of rapeseed in mixture is much greater than would be predicted. This observation, that the RY of rapeseed in mixture is equal to, or greater than, that predicted from pure stands implies that interference by *B. pectinatus* on rapeseed is negligible.

Rapeseed would be a valuable smother crop for use in crop rotations attempting to suppress *B. pectinatus*. Rapeseed was unaffected by *B. pectinatus* interference and *B. pectinatus* responded to rapeseed interference by decreasing culm production.

Spatial Effects Of Interference Between Wheat And *Bromus pectinatus* Thunb.

Interspecfic competition between wheat and *B. pectinatus* is more detrimental, at field row spacing, than is intraspecific competition in wheat (Table 11A). On average there was twice as many culms, and 40% more dry matter in wheat plants which grew with interference by other wheat plants, rather than wheat plants which grew with interference by *B. pectinatus*. *B. pectinatus* appears to be more effective than wheat in interfering with wheat above ground. Wheat plants were tallest when there was below ground interference only. However, when there was no interference, wheat plant height was still shorter than when wheat interfered with wheat, or when *B. pectinatus* interfered below ground. The implication is that below ground interference with wheat will promote an increase in wheat shoot height provided that above ground interference by *B. pectinatus* is absent.

The increase in wheat plant height with below ground interference

Table 11. Spatial interference between wheat and Bromus pectinatus Thunb. and its influence on yield components of A)WHEAT and B) B. pectinatus .

A)WHEAT

INTERFERENCE	DRY MATTER (g)	PLANT HEIGHT (cm)	CULM NUMBER	HEAD NUMBER
BY OTHER WHEAT PLANTS	5.6 a[1.]	61 ab	7.7 a	3.0 a
ABOVE GROUND ONLY	3.3 b	55 b	4.3 b	1.5 b
BELOW GROUND ONLY	3.8 b	67 a	4.2 b	1.5 b
ABOVE & BELOW GROUND	3.3 b	56 b	4.8 b	1.5 b
NO INTERFERENCE	3.1 b	56 b	4.2 b	1.5 b
Average	3.8	59	5.0	1.8
C.V.	17	9	17	25
$LSD_{.05}$	1.0	7.6	1.3	0.7

B)B. pectinatus Thunb.

INTERFERENCE	DRY MATTER (g)	PLANT HEIGHT (cm)	CULM NUMBER	HEAD NUMBER
ABOVE GROUND ONLY	3.4 a[1.]	63 a	3.3 ab	0.5 ab
BELOW GROUND ONLY	1.2 b	48 b	1.9 b	0.2 b
ABOVE & BELOW GROUND	4.1 a	56 ab	4.6 a	0.5 ab
NO INTERFERENCE	3.8 a	63 a	4.0 ab	0.7 a
Average	3.1	57	3.4	0.5
C.V.	19	12	47	49
$LSD_{.05}$	0.97	11.1	2.54	0.37

[1.] Numbers in the same column followed by the same letter do not differ significantly ($P < .05$) according to the LSD test.

by *B. pectinatus* occurred at the expense of *B. pectinatus* shoot growth. Shoot dry matter, plant heights, and panicles produced on *B. pectinatus* were all reduced with below ground interference, compared to any other *B. pectinatus* treatment (Table 11B).

The below ground interference of wheat on *B. pectinatus* is not likely due to the release of allelochemicals into the soil by wheat. The below ground interference did not occur when *B. pectinatus* was allowed to interfere with the wheat above ground. Above ground interference by *B. pectinatus* must be more important than below ground interference. Aldrich (1984) states that when plants are in competition, competition for light takes precedence over competition for below ground factors.

The interpretation of these results is that the main *B. pectinatus* interference on wheat occurs above ground, whereas, wheat mainly interferes with *B. pectinatus* below ground. However, this experiment was conducted in a shadehouse and in a shallow soil profile. In the field, under bright sunlight, above ground interference for light might be less important. Both wheat and *B. pectinatus* are C_3 species (Imbamba, 1979) and would likely receive more than their saturation requirements in the bright tropical sun - even with interference. In the field the plants would have a greater soil profile than used in this experiment. These conditions would allow complementation of root distribution and reduce below ground competition. Based on field observations in Kenyan fields this complementation does occur. *B. pectinatus* roots tend to be finer, and more shallowly distributed, than roots of Kenyan wheat cultivars. *Bromus* species roots are characteristically long, fragile, and fine (Hulbert, 1955).

CHAPTER 6

Chemical Control of *Bromus pectinatus* Thunb.

ABSTRACT

In 1982 and 1983 several herbicides were evaluated in Kenya for their ability to control *Bromus pectinatus* Thunb. in wheat (*Triticum aestivum*) and rapeseed (*Brassica napus*). In 1982 the herbicides triallate, chlorsulfuron, and metribuzin were found to partially reduce the levels of *B. pectinatus* infestation. Under the drier conditions of 1983, these three herbicides were ineffective against *B. pectinatus*. Trifluralin was observed to be effective against *B. pectinatus* only at rates which injured the wheat. Isoproturon and pendimethalin were ineffective against *B. pectinatus* in wheat. The herbicides fluazifop-butyl and fenthiaprop-ethyl gave excellent control of *B. pectinatus* in rapeseed. Limited control of *B. pectinatus* in rapeseed was achieved with the herbicides triallate, trifluralin and EPTC. Oxadiazon and pendimethalin were ineffective against *B. pectinatus* and caused rapeseed injury. In pot trials, low rates of glyphosate were effective against *B. pectinatus* and control was growth stage dependent. In the field, effective control of *B. pectinatus* can be achieved using a crop rotation including rapeseed into which either fluazifop-butyl or fenthiaprop-ethyl is applied.

INTRODUCTION

Successful use of herbicides for control of wild oats (*Avena fatua*) and ryegrass (*Lolium* species) in Kenyan cereals, opened a niche which became filled with the weedy annual grass *Bromus pectinatus* (Stobbe, 1983). As a weed problem *B. pectinatus* is unique to East Africa and

Turkey (Pollard *et al*, 1984). Except for some research in Kenya by Kenya Breweries Ltd. (Owino and Little, 1979) and recently in Great Britain (Richardson *et al.*, 1983; Pollard *et al.*, 1984; Richardson and Pollard, 1984) little information exists on the control of *B. pectinatus* with herbicides. In Kenya there are no herbicides recommended for control of *B. pectinatus* in wheat (Anonymous, 1983). Triallate at 2.4 kg/ha is recommended for control of *Bromus* species in barley (Owino *et al.*, 1983). Triallate at 2.4 kg/ha does not give complete control, and *B. pectinatus* will persist to the next cropping season. Limited control of *B. pectinatus* increases the risk of herbicide resistant types surviving and increasing (Parker, 1977). This survival and increase has been observed in wild oats by Thai *et al.* (1985) and has been predicted by Parker (1977):

> "Particular problems may arise from species which do not occur in developed agriculture and for which none of the available herbicides is selective".

Growing rapeseed (*Brassica napus*) in rotation with cereals has recently become a viable alternative to monoculture cereals for many Kenyan farmers. *B. pectinatus* has also become a weed of this relatively new crop to Kenya. The use of this broadleaved crop in rotation with cereals has improved the range of herbicides which can be applied to control *B. pectinatus*. Crop rotations also improve the opportunities to rotate herbicides with different modes of action. When properly managed, rotating herbicides prevent changes in weed flora (such as that which allowed *B. pectinatus* to become a major weed) from occurring (Parker, 1977).

This paper reports the results of herbicide trials conducted in Kenya during 1982 and 1983 for control of *B. pectinatus* in wheat and rapeseed.

MATERIALS AND METHODS

Herbicides For Use In Wheat

All wheat herbicide trials were conducted at the KBL research station, Mau Narok. The KBL research station has a clay loam soil with 7% organic matter and a pH of 5.2.

All wheat trials had 4 replicates of each treatment arranged in a randomized complete block design. *B. pectinatus* counts and wheat yields were analysed using the least significant difference (LSD) test, at the 5% level of significance following analysis of variance (ANOVA). Only those differences detected by the LSD test were considered meaningful. Visual assessments were not analysed statistically.

1982 Wheat trials

The 1982 trials were applied to a site which was sown to wheat (cv. Kenya Paa), at a 100 kg/ha sowing rate, along with 100 kg/ha monoammonium phosphate fertilizer. The copper dressed wheat was sown with a double disc research drill planting to a depth of 5 cm. Sowing was carried out on July 13, except for Experiment 1 which was sown on July 24. On August 24 the density of *B. pectinatus* in each plot was assessed using three 1/4 m^2 random quadrats. A blanket treatment of Maytril at a 2.5 kg/ha rate was applied on September 14 to control broadleaved weeds in the plot area. On November 23, the experiments were visually assessed for both *B. pectinatus* control and crop injury

according to European Weed Research Council (EWRC) rating system (Appendix 3 and 4). Experiments were harvested on January 18, 1983 with a plot combine.

Plot size was 2.5 m x 10 m in which a 2 m wide strip down the center of each plot was treated. Treatments were applied using a 4 nozzle (50 cm spacing) bicycle sprayer. Compressed air supplied 2.5 bars pressure to the stainless steel flat fan nozzles (Spraying Systems Co., Tee Jet 6502). The spraying speed was 1 m/sec. The total volume application rate, as determined by sprayer calibration was 224 l/ha. All herbicides were applied to moist soil under cool, cloudy conditions.

Experiment 1. Control of *B. pectinatus* using triallate

Pre-plant incorporated (ppi) triallate treatments were applied on July 21 and incorporated within 25 minutes of application with a diamond toothed harrow. Pre-emergent incorporated (pei) treatments were applied on July 24 and incorporated within 10 minutes of spray application with nail toothed garden rakes. In both ppi and pei trials, incorporation was in one direction and then 90° to the first direction.

Experiment 2. Control of *B. pectinatus* with isoproturon and chlorsulfuron

Isoproturon and chlorsulfuron were applied pre-emergent (pre) on July 17 and post-emergent (poe) on August 6. The poe treatments were applied to *B. pectinatus* in the 1-2 leaf stage and wheat in the 2-3 leaf stage.

Experiment 3. Control of *B. pectinatus* with metribuzin

Metribuzin was applied pre on July 17. On August 6 metribuzin was applied poe, to *B. pectinatus* in the 1-2 leaf stage and wheat in the 2-3 leaf stage.

1983 Wheat trials

The 1983 site was sown with a double-disc research drill set to a depth of 5 cm on July 12. Copper dressed seed and diammonium phosphate fertilizer were sown together, each at a rate of 100 kg/ha. Due to seedbag mislabeling, the first replicate and about 1/2 the second replicate were sown to triticale (cv. T65). The remainder of the second replicate and the third and fourth replicates were sown with wheat (cv. Tembo). In this report, the term wheat, as used for the 1983 trials, actually refers to the triticale-wheat mixture as previously described. In these trials the triticale and wheat responded similarly to the herbicides. Broadleaved weeds were controlled at the trial site with application of 2.5 l/ha of Maytril on August 10. Visual assessment of crop injury, using EWRC scoring, was determined on September 7 for experiment 6, and on September 15 for experiments 4 and 5. *B. pectinatus* density was assessed on the same respective dates using three random 1/2 m^2 quadrats/plot. On December 22 the plots were visually assessed for *B. pectinatus* control using EWRC scoring. Experiments were harvested on January 19, 1984, with a plot combine.

Except for experiment 6, where plot size was 4 m x 10 m and a strip 3.5 m x 10 m down the center was sprayed, plot size was 2.5 m x 10 m in which a strip 2 m x 10 m down the center of each plot was sprayed. In the wider plots a 7 nozzle (50 cm spacing) bicycle sprayer with

stainless steel flat fan nozzles (Spraying Systems Co., Tee Jet 80015) was used, while in the smaller plots only 4 of the nozzles (50 cm spacing) were used. The spraying speed was 1 m/sec and compressed air provided a sprayer pressure of 2.5 bars. With this combination, the total volume application rate used, as determined by sprayer calibration, was 176 l/ha.

Except for trifluralin, which was sprayed on dry soil under warm cloudy conditions, all treatments were applied on to moist soil under cool and cloudy conditions. Immediately after pendimethalin application there was a heavy rain.

The triallate and trifluralin treatments were incorporated within 30 minutes of application. Incorporation was first in one direction and then 90° to the first direction. The triallate was incorporated using short firm back and forth strokes with a garden rake, whereas, the trifluralin was incorporated using spike-toothed harrows.

Experiment 4. Control of *B. pectinatus* with triallate and with isoproturon

Triallate was applied pei on July 15. Isoproturon was applied poe to *B. pectinatus* in the 3 to 4 leaf stage and wheat in the 4 leaf stage.

Experiment 5. Control of *B. pectinatus* with chlorsulfuron and metribuzin

Chlorsulfuron, metribuzin and the chlorsulfuron-metribuzin mixture were applied poe to *B. pectinatus* in the 3-4 leaf stage and to wheat in the 4 leaf stage.

Experiment 6. Control of *B. pectinatus* with trifluralin and with pendimethalin

On July 14 trifluralin was applied pei and pendimethalin was applied pre.

Herbicides For Use In Rapeseed

All rapeseed herbicide trials were conducted at the KBL research station, Mau Narok, except for Experiments 8b and 9b which were conducted at Muthera farm near Mau Narok.

All experiments had 4 replicates of each treatment arranged in a randomized complete block design. Rapeseed and *B. pectinatus* densities and rapeseed yields were analysed by ANOVA and the LSD test performed on the results. Only those values which were significant at the 5% level were considered meaningful.

1982 Rapeseed trial

Experiment 7. Control of *B. pectinatus* with fluazifop-butyl, 1982

The experiment was conducted in a commercially planted rapeseed field (cv. Regent) which was sown on July 6, 1982. The rate of seeding was 8 kg/ha, and depth of seeding was 2 to 4 cm. The formulation of fluazifop-butyl used (Fusilade "W") also contained a commercial wetter.

Fluazifop-butyl was sprayed poe on July 24 to *B. pectinatus* and rapeseed in the 2-4 leaf stage and on July 30 to *B. pectinatus* in the 3-4 leaf stage and rapeseed in the 4 leaf stage. Spraying on both dates was conducted under cloudy and cool conditions over plants growing in moist soil.

The fluazifop-butyl was applied using a 4 nozzle (50 cm spacing)

bicycle sprayer. Pressure, supplied by compressed air was 2.5 bars, except for the 0.07 and 0.15 application rates (July 30) where due to a technical error, pressure was 1.25 bars. The spraying speed was 1 m/sec and stainless steel flat fan nozzles (Spraying Systems Co., Tee Jet 6502) were used. With this combination, it was determined by calibration, that at 2.5 bars, the total volume application rate was 224 l/ha, and at 1.25 bars, was 116 l/ha.

Visual assessment of *B. pectinatus* control and rapeseed injury, using the EWRC scale was conducted on August 9 for the early sprayed treatments and on August 17 for the later sprayed treatments. No yields were taken.

1983 Rapeseed trials

Except for experiments 8b and 9b all experiments were placed on a commercially sown field of rapeseed. The rapeseed (cv. Regent) was sown at a depth of 2 cm with a pneumatic air drill. Sowing rate was 8 kg/ha and no fertilizer was applied.

In experiments 8, 9 and 12 plot size was 2.5 m x 10 m in which a strip 2.0 m x 10 m down the center of each plot was sprayed with a 4 nozzle (50 cm spacing) bicycle sprayer. With experiments 10, 11 and 13 the plot size was 4.0 m x 10 m in which a strip 3.5 m x 10 m down the center of each plot was sprayed with a 7 nozzle (50 cm spacing) bicycle sprayer. The spraying speed was 1 m/sec and compressed air provided a sprayer pressure of 2.5 bars. With this combination, the total volume application rate, as determined by sprayer calibration, was 176 l/ha.

Soil incorporated herbicide plots were evaluated for *B. pectinatus* and rapeseed density, on September 7, using three random 1 m^2 quadrats

in each plot. With postemergent herbicide treatments similar plot measurements were taken on September 15. On February 23, 1984, two 1 m^2 samples were hand harvested from each plot, threshed in a stationary small plot thresher, and seed yields recorded.

Except for pendimethalin in experiment 11, which was applied under warm conditions, all herbicides were applied under cloudy and cool conditions to a moist soil. There was rain immediately after the pendimethalin application. Incorporated herbicides were incorporated using a spike-toothed harrow, first in one direction, and then 90° to the first direction.

Experiments 8b and 9b were conducted at the Muthera farm, near Mau Narok. The treatments were applied over rapeseed (cv. Cressor) sown at a 6 kg/ha seeding rate with a double disc research drill. Treatments were applied to rapeseed in the 6 leaf stage and to *B. pectinatus* (at densities averaging 113 plants/m^2) at the 4 leaf stage. However, due to difficulties with baboons the only data collected was *B. pectinatus* plant counts from two 1 m^2 quadrats per plot on September 22.

Experiment 8a. Control of *B. pectinatus* with fluazifop-butyl, Kenya Breweries Ltd.

This experiment was conducted at the Kenya Breweries Ltd. research station. Fluazifop-butyl was sprayed on August 25 to rapeseed in the 6 leaf stage and *B. pectinatus* in the 4 leaf stage.

Experiment 8b. Control of *B. pectinatus* with fluazifop-butyl, Mathera Farm.

This experiment was conducted at Muthera farm, Mau Narok. Fluazifop-butyl was sprayed on September 1 onto rapeseed in the 6 leaf stage and *B. pectinatus* in the 4 leaf stage.

Experiment 9a. Control of *B. pectinatus* with fenthiaprop-ethyl, Kenya Breweries Ltd.

This experiment was conducted at the Kenya Breweries Ltd. research station. Fenthiaprop-ethyl was sprayed on August 25 to rapeseed in the 6 leaf stage and *B. pectinatus* in the 4 leaf stage.

Experiment 9b. Control of *B. pectinatus* with fenthiaprop-ethyl, Muthera Farm.

This experiment was conducted at Muthera Farm, Mau Narok. Fenthiaprop-ethyl was sprayed on September 1 onto rapeseed in the 6 leaf stage and *B. pectinatus* in the 4 leaf stage.

Experiment 10. Control of *B. pectinatus* with triallate

Triallate was applied ppi on July 7 and was incorporated within 2-1/2 hours of application. Triallate was also applied to plots pei on July 14 and incorporated within 1-1/2 hours of application.

Experiment 11. Control of *B. pectinatus* with trifluralin and pendimethalin

Trifluralin was applied ppi on July 7 and was incorporated within 3 hours of application. Pendimethalin was applied pre on July 14.

Experiment 12. Control of *B. pectinatus* with oxadiazon

Oxadiazon was applied pre on July 15.

Experiment 13. Control of *B. pectinatus* with EPTC

EPTC was applied ppi on July 12 and was incorporated within 15 minutes of application.

General Use Herbicides

Experiment 14. Glyphosate efficacy against pot grown *B. pectinatus*

On August 9, 1982, at the KBL research station near Mau Narok, thirty-six 20 cm diameter, 4 litre plastic pots were filled with loam soil from a KBL field. Fifteen *B. pectinatus* plants, at the one leaf stage, naturally growing in the field, were carefully transplanted into each of the 36 pots. The pots were then transported to the National Plant Breeding Station, Njoro, and grown in a shadehouse.

For each treatment the pots were placed in a trench the same depth as the pots. A bicycle sprayer, spraying at the appropriate rate was then pushed over the pots in the trench. At all treatment dates spraying was conducted in the morning under sunny calm, humid conditions. A surfactant (DSK) was added at a 5% (V/V) rate to the two lowest rates of glyphosate to improve efficacy.

The bicycle sprayer consisted of 4 stainless steel flat fan nozzles (Spraying Systems Co., Tee Jet 8502) spaced 50 cm apart. Speed of the bicycle sprayer was 1 m/sec and compressed air supplied a sprayer pressure of 2.5 bars. With this combination it was determined by calibration that the nozzle output was equivalent to 224 l/ha.

Treatments consisted of spraying the plants with either a 0.178, 0.534 and 1.068 kg/ha rate of glyphosate at the 3 leaf, mid-tillering, and panicle emergence stages of growth. Pots were arranged in the shadehouse in a randomized complete block design with 4 replications.

The *B. pectinatus* plants were evaluated for survival soon after it was apparent that the plants had stabilized in either a dead or living condition. Evaluation of the 3 leaf and mid-tillering sprayed plants was on September 23 and evaluation of panicle emergence sprayed plants was on October 22.

Plant survival and culm numbers were analysed using the LSD test at the 5% significance level following ANOVA. Only those differences detected by the LSD test were considered meaningful.

RESULTS AND DISCUSSION

Herbicides For Use In Wheat

1982 Wheat trials

The herbicide trials conducted in wheat during 1982 indicated that triallate, chlorsulfuron, and metribuzin were effective against *B. pectinatus*.

Triallate, applied both ppi and pei, at the 1.6 and 2 kg/ha rates, was effective in reducing the initial *B. pectinatus* infestation (Table 12). However, visual assessment later in the season, determined that none of the triallate treatments provided adequate *B. pectinatus* control. The number of *B. pectinatus* plants that survived the triallate treatments was still adequate to compete with the wheat.

Chlorsulfuron, applied at 0.026 kg/ha poe, caused reduction in *B. pectinatus* infestation (Table 13). The other rates were ineffective against *B. pectinatus*. Visual assessment also gave the 0.026 kg/ha poe rate an adequate score (EWRC value = 4).

Isoproturon was found to be ineffective against *B. pectinatus* (Table 13).

Metribuzin had no significant influence on *B. pectinatus* infestation, but using a visual assessment later on in the growing season, poe metribuzin applications were found to be very effective against *B. pectinatus* (Table 14). Increased yields were observed in all metribuzin treated plots (both pre and poe). Plots treated with metribuzin had higher yields than the untreated plots.

Table 12. Control of *Bromus pectinatus* Thunb. and yield of wheat using Triallate, 1982[1].

TREATMENT	HERBICIDE RATE (Kg/ha ai)	*B. pectinatus* COUNTS (plants/m^2)	GRAIN YIELD (g/m^2)	MEDIAN VISUAL SCORING[2]	GRAIN YIELD (g/m^2)
untreated	-	184 a[3]	266	9.0	266
ppi triallate	1.2	160 ab	328	6.0	328
" "	1.6	108 b	313	5.5	313
" "	2.0	104 b	277	5.0	277
pei triallate	1.2	128 ab	276	5.5	276
" "	1.6	120 b	274	5.0	274
" "	2.0	116 b	277	5.5	277
AVERAGE		131.6	287	-	287
C.V.		24	19	-	19
$LSD_{.05}$		63.6	n.s.	-	n.s.

[1] average of 4 replicates

[2] using EWRC scoring for weed control

[3] numbers in the same column followed by the same letter do not differ significantly ($P \leq .05$) according to the LSD test

CROP INJURY : no crop injury was observed, EWRC scoring for all treatments = 1 .

Table 13. Control of Bromus pectinatus Thunb.[1] and yield of wheat using isoproturon or chlorsulfuron, 1982[1].

TREATMENT	HERBICIDE RATE (kg/ha ai)	B. pectinatus COUNTS (plants/m^2)	MEDIAN VISUAL SCORING[2]	GRAIN YIELD (g/m^2)
untreated	-	128 ab[3]	9.0	306
pre chlorsulfuron	0.011	148 a	8.0	331
" "	0.019	144 a	8.0	344
" "	0.026	148 a	6.0	339
poe chlorsulfuron	0.011	140 ab	8.5	341
" "	0.019	132 ab	8.0	350
" "	0.026	72 c	4.0	299
pre isoproturon	3.0	128 ab	6.5	337
" "	4.0	120 ab	6.0	357
" "	6.0	104 abc	6.5	367
poe isoproturon	1.5	144 a	7.0	353
" "	2.0	96 bc	5.5	367
" "	3.0	116 abc	6.0	374
AVERAGE		124.8	-	343.5
C.V.		19	-	10
$LSD_{.05}$		46.4	-	n.s.

[1] average of 4 replicates

[2] using EWRC scoring for weed control

[3] numbers in the same column followed by the same letter do not differ significantly ($P \leq .05$) according to the LSD test

CROP INJURY : no crop injury was observed. EWRC scoring for all treatments = 1 .

Table 14. Control of Bromus pectinatus Thunb. and yield of wheat using metribuzin, 1982[1].

TREATMENT	HERBICIDE RATE (kg ai /ha)	B. pectinatus COUNTS (plants/m^2)	MEDIAN VISUAL SCORING[2]	GRAIN YIELD (g/m^2)
untreated	-	124	9.0	298 b[3]
pre metribuzin	0.2	108	7.0	355 a
" "	0.3	128	7.0	325 ab
" "	0.4	76	8.0	347 a
poe metribuzin	0.2	80	3.0	353 a
" "	0.3	52	3.0	351 a
" "	0.4	80	2.5	340 a
AVERAGE		92.4	-	338.4
C.V.		48	-	8
$LSD_{.05}$		n.s.	-	39.6

[1] average of 4 replicates

[2] using EWRC scoring for weed control

[3] numbers in the same column followed by the same letter do not differ significantly ($P < .05$) according to the LSD test

CROP INJURY: no crop injury was observed, EWRC scoring for all treatments = 1

There was no crop injury by any herbicides and rates tried in 1982.

1983 Wheat trials

Triallate was not as effective in 1983 as it was in 1982. Visual assessment indicated that there was some control of *B. pectinatus* with triallate (Table 15).

In 1983, isoproturon, as in 1982, was found to be ineffective against *B. pectinatus*.

Chlorsulfuron, metribuzin and chlorsulfuron-metribuzin mixtures were found to be ineffective against *B. pectinatus* (Table 16). The high rate of metribuzin (0.280 kg/ha) caused some slight chlorosis in the wheat.

Trifluralin was effective against *B. pectinatus* as indicated by both *B. pectinatus* counts and visual scoring (Table 17). However, at the rates of trifluralin found effective (1.2 and 1.4 kg/ha) there was significant crop injury.

Pendimethalin at the 1.5 kg/ha rate appears to have partially controlled *B. pectinatus* on the basis of plant counts and visual scoring (Table 17). However, this control did not occur with the higher rates and may, therefore, be an anomally.

On the basis of the results obtained in the wheat trials none of the herbicides tested could be recommended for controlling *B. pectinatus* in wheat. The 1982 and 1983 results indicate that none of the herbicides consistantly gave satisfactory results. Isoproturon and pendimethalin were not effective against *B. pectinatus*. The herbicide trifluralin was effective against *B. pectinatus*, but only at rates which injured the wheat crop. Triallate, metribuzin and chlorsulfuron

Table 15. Control of Bromus pectinatus Thunb. and yield of wheat using triallate or isoproturon, 1983 [1].

TREATMENT	HERBICIDE RATE (kg ai/ha)	B. pectinatus COUNTS (plants/m^2)	MEDIAN VISUAL SCORING [2]	GRAIN YIELD (g/m^2)
untreated 1	-	8	9.0	257
" 2	-	14	9.0	242
" 3	-	8	9.0	253
" 4	-	4	9.0	274
" 5	-	8	9.0	248
pei triallate	1.2	10	6.5	273
" "	1.6	6	6.5	298
" "	2.0	4	7.5	254
poe isoproturon	1.5	10	9.0	295
" "	2.0	10	9.0	275
" "	3.0	10	9.0	310
AVERAGE		9.8	-	270.7
C.V.		87	-	13
$LSD_{.05}$		n.s.	-	n.s.

[1] average of 4 replicates

[2] using EWRC scoring for weed control

CROP INJURY : no crop injury was observed, EWRC scoring for all treatments = 1

Table 16. Control of *Bromus pectinatus* Thunb.[1] and yield of wheat using chlorsulfuron and metribuzin, 1983.

TREATMENT	HERBICIDE RATE (kg ai/ha)	MEDIAN CROP INJURY[2]	*B. pectinatus* COUNTS (plants/m^2)	MEDIAN VISUAL SCORING[3]	GRAIN YIELDS (g/m^2)
untreated 1	-	1.0	8	9.0	328 abc[4]
untreated 2	-	1.0	8	9.0	271 de
poe chlorsulfuron	0.0038	1.0	8	9.0	338 a
" "	0.0075	1.0	16	9.0	275 cde
" "	0.015	1.0	8	9.0	308 a-e
" "	0.030	1.0	10	9.0	281 cde
poe chlorsulfuron/ metribuzin	0.0038/ 0.070	1.0	10	9.0	335 ab
" "	0.0038/ 0.015	1.0	12	9.0	284 b-e
" "	0.0038/ 0.140	1.0	8	9.0	299 a-e
" "	0.0075/ 0.070	1.0	8	9.0	268 de
" "	0.0075/ 0.105	1.0	8	9.0	347 a
" "	0.0075/ 0.140	1.0	10	9.0	255 e
poe metribuzan	0.070	1.0	10	9.0	295 b-e
" "	0.105	1.0	8	9.0	283 b-e
" "	0.140	1.0	8	9.0	310 a-d
" "	0.280	2.0	8	9.0	261 de
AVERAGE		-	9.2	296.0	-
C.V.		-	43	12	-
$LSD_{.05}$		-	n.s.	52.5	-

[1] average of 4 replicates

[2] using EWRC scoring for crop injury

[3] using EWRC scoring for weed control

[4] numbers in the same column followed by the same letter do not differ significantly ($P<.05$) according to the LSD test

Table 17. Control of Bromus pectinatus Thunb.[1] and yield of wheat using trifluralin or pendimethalin, 1983[1].

TREATMENT	HERBICIDE RATE (kg ai/ha)	MEDIAN CROP INJURY[2]	B. pectinatus COUNTS (plants/m^2)	MEDIAN VISUAL SCORING[3]	GRAIN YIELDS (g/m^2)
untreated	-	1.0	20 a[4]	9.0	243 abc
pre trifluralin	0.6	2.5	16 ab	4.5	251 abc
" "	0.8	4.0	10 abc	3.5	303 ab
" "	1.0	5.5	10 abc	3.5	275 ab
" "	1.2	5.0	2 c	3.0(1-5)	294 ab
" "	1.4	6.0	2 c	1.0	255 abc
pre pendimethalin	1.5	1.0	8 bc	5.5	322 a
" "	2.0	1.0	12 abc	8.0	229 bc
" "	2.5	1.0	16 ab	9.0	183 c
" "	3.0	1.0	14 ab	8.5	187 c
AVERAGE		-	11.0	-	254.2
C.V.		-	71	-	21
$LSD_{.05}$		-	11.2	-	79.9

[1] average of 4 replicates

[2] using EWRC scoring for crop injury

[3] using EWRC scoring for weed control

[4] numbers in the same column followed by the same letter do not differ significantly ($P < .05$) according to the LSD test.

performed well one year but did not have similar efficacy in the following years trials.

The effective control of *B. pectinatus* by poe chlorsulfuron, and not pre chlorsulfuron, at 0.026 kg/ha was unexpected (Table 13). Other *Bromus* species have been adequately controlled by pre applications of chlorsulfuron at the low rate of 0.008 kg/ha (Levitt *et al.*, 1981).

In 1982, metribuzin was effective against *B. pectinatus* competition in wheat, resulting in a yield increase. This efficacy of metribuzin is in agreement with other authors who have observed effective control of other *Bromus* species with metribuzin (Richardson and Pollard, 1984; Carmean and Russ, 1982; Fischer and Peeper, 1981; Greer *et al.*, 1980; Gigax, 1979; Stanley and Cagle, 1979; Runyan and Peeper, 1979a).

Triallate could not be recommended for *B. pectinatus* control in wheat based on the 1982 results. The highest rate of triallate tested, based on economic considerations, was 2.0 kg/ha, and this rate gave only partial control of *B. pectinatus*. Even the partial control by triallate, observed in 1982, was reduced under 1983 conditions. In barley, in Kenya, triallate is recommended for *Bromus* species control at a 2.4 kg/ha rate (Owino *et al.*, 1983).

Variability in efficacy between the years 1982 and 1983, for the poe herbicides, may be explained on the basis of leaf stage at spraying. In 1982 the poe herbicides were applied to *B. pectinatus* plants at the 1 to 2 leaf stage, whereas in 1983 poe herbicide applications were applied to 3 to 4 leaf *B. pectinatus*. Chlorsulfuron and metribuzin may have been more effective against *B. pectinatus* when applied at the 1 to 2 leaf stage rather than at the 3 to 4 leaf stage. With metribuzin, early post-emergent applications are recommended for best results (WSSA,

1983).

The different environmental conditions experienced in 1982 and 1983 may also account for the better performance of triallate, metribuzin and chlorsulfuron against *B. pectinatus* in 1982 than in 1983. At Mau Narok the precipitation pattern was more uniform in 1982 than in 1983. The increased activity of triallate, metribuzin and chlorsulfuron in 1982, compared to 1983, may have occurred because of increased soil activity at the higher moistures.

Herbicides For Use In Rapeseed

1982 Rapeseed trial

Fluazifop-butyl applied at a rate of 0.5 and 1.0 kg/ha was found to give adequate control of *B. pectinatus* plants in the 2 to 4 leaf and 3 to 4 leaf stage (Table 18). Control was assessed visually using EWRC scoring. There was no apparent injury to the rapeseed due to treatment.

1983 Rapeseed trials

Fluazifop-butyl, applied poe, provided excellent control of the *B. pectinatus* population with rates as low as 0.25 kg/ha (Table 19). Fenthiaprop-ethyl, applied poe, also provided excellent control of *B. pectinatus*, at a rate as low as 0.12 kg/ha (Table 20). Near complete control was also achieved with fluazifop-butyl and fenthiaprop-ethyl, when applied at similar rates, at the Muthera Farm site (Data not presented). Both fluazifop-butyl and fenthiaprop-ethyl are known to be highly selective post-emergence grass killers and thus they would be expected to be effective against *B. pectinatus*.

Triallate applied at rates of 1.2 to 2.0 kg/ha ppi, and 2.0 kg/ha

Table 18. Control of Bromus pectinatus Thunb[1] and yield of rapeseed using fluazifop-butyl, 1982.

TREATMENT	HERBICIDE RATE (kg ai/ha)	MEDIAN VISUAL SCORING[2]
untreated	-	9.0
poe fluazifop-butyl (early)	0.125	7.0
" "	0.25	5.0
" "	0.5	4.5
" "	1.0	3.0
poe fluazifop-butyl (late)	0.07	7.0
" "	0.15	7.0
" "	0.5	4.0
" "	1.0	2.5

[1] average of 4 replicates

[2] using EWRC scoring for weed control

CROP INJURY ; no crop injury was observed, EWRC scoring for all treatments = 1

Table 19. Control of Bromus pectinatus Thunb. and yield of rapeseed using fluazifop-butyl, 1983 [1].

TREATMENT	HERBICIDE RATE (Kg ai/ha)	RAPESEED COUNTS (plants/m^2)	B. pectinatus COUNTS (plants/m^2)	SEED YIELD (g/m^2)
untreated	-	17	13.a[2]	195.3
poe fluazifop-butyl	0.25	24	1 b	232.4
" "	0.38	20	1 b	242.4
" "	0.50	18	0 b	227.9
" "	0.63	19	0 b	224.8
" "	0.75	19	0 b	244.9
AVERAGE		19.5	3.0	228.0
C.V.		31	77	21
$LSD_{.05}$		n.s.	4.0	n.s.

[1] average of 4 replicates

[2] numbers in the same column followed by the same letter do not differ significantly ($P<.05$) according to the LSD test

CROP INJURY : no crop injury was observed, EWRC scoring for all treatments = 1

Table 20. Control of Bromus pectinatus Thunb. and yield of rapeseed using fenthiaprop-ethyl, 1983[1].

TREATMENT	HERBICIDE RATE (kg ai/ha)	RAPESEED COUNTS (plants/m^2)	B. pectinatus COUNTS (plants/m^2)	SEED YIELD (g/m^2)
untreated	-	16	12 a[2]	293.1
poe fenthiaprop-ethyl	0.12	17	1 b	254.0
" "	0.24	18	1 b	244.0
" "	0.36	13	1 b	294.1
" "	0.48	20	0 b	286.5
" "	0.60	18	0 b	233.6
" "	0.72	17	0 b	261.6
AVERAGE		17	2.2	266.7
C.V.		27	107	18
$LSD_{.05}$		n.s.	3.2	n.s.

[1] average of 4 replicates

[2] numbers in the same column followed by the same letter do not differ significantly ($P \leq .05$) according to the LSD test

CROP INJURY : no crop injury was observed, EWRC scoring for all treatments = 1

pei, partially reduced the *B. pectinatus* infestation in rapeseed (Table 21). The triallate results in rapeseed were consistent with the results observed for triallate in wheat in 1982 (Table 12).

At a 0.6 and 1.2 kg/ha rate, ppi trifluralin provided some control of *B. pectinatus*, and at the 1.4 kg/ha rate ppi, of trifluralin, control was excellent (Table 22). These results in rapeseed are consistent with the observations in wheat in 1983 (Table 17). The results also are in agreement with the WSSA (1983) who recommend trifluralin at rates 0.6 to 1.1 kg/ha to control the annual grasses *B. tectorum* and *B. secalinus*.

Pendimethalin at the 1.5 kg/ha rate provided some control of *B. pectinatus* (Table 22). However, this control did not occur with the higher rates and may be an anomally. In rapeseed, even the low rate of 1.5 kg/ha pendimethalin caused crop injury.

Oxadiazon does not control *B. pectinatus* in rapeseed. It was not only ineffective in controlling *B. pectinatus* but also caused extensive rapeseed thinning (Table 23).

The herbicide EPTC was partially effective in controlling *B. pectinatus* at all rates tested (Table 24). These observations are consistent with the observation by Pollard *et al.* (1984) that *B. pectinatus* and other *Bromus* species were selectively controlled with EPTC in winter barley.

General Use Herbicides

Glyphosate efficacy against pot-grown *B. pectinatus*

Glyphosate was 100% effective against *B. pectinatus* at all growth stages when applied at a 0.534 and 1.068 kg/ha rate (Table 25).

Table 21. Control of *Bromus pectinatus* Thunb. and yield of rapeseed using triallate, 1983 [1].

TREATMENT	HERBICIDE RATE (kg ai/ha)	RAPESEED COUNTS (plants/m^2)	*B. pectinatus* COUNTS (plants/m^2)	SEED YIELD (g/m^2)
untreated	-	21	10 a [2]	276.2
ppi triallate	1.2	19	3 c	278.6
" "	1.6	17	3 c	287.7
" "	2.0	17	4 bc	267.7
pei triallate	1.2	19	6 abc	242.0
" "	1.6	18	8 ab	229.6
" "	2.0	18	5 bc	188.6
AVERAGE		18.4	5.6	252.9
C.V.		22	61	28
$LSD_{.05}$		n.s	4.8	n.s.

[1] average of 4 replicates

[2] numbers in the same column followed by the same letter do not differ significantly ($P < .05$) according to the LSD test

CROP INJURY : no crop injury was observed, EWRC scoring all treatments = 1

Table 22. Control of Bromus pectinatus Thunb. and yield of rapeseed using trifluralin or pendimethalin, 1983[1].

TREATMENT	HERBICIDE RATE (kg ai/ha)	RAPESEED COUNTS (plants/m^2)	B. pectinatus COUNTS (plants/m^2)	SEED YIELD (g/m^2)
untreated	-	14 a[2]	7 a	259.4
ppi trifluralin	0.6	14 a	3 bc	325.2
" "	0.8	11 ab	4 b	290.0
" "	1.0	16 a	4 b	281.5
" "	1.2	15 a	4 b	368.3
" "	1.4	13 ab	1 c	368.1
pre pendimethalin	1.5	8 bc	4 b	301.6
" "	2.0	5 c	5 ab	316.6
" "	2.5	4 c	7 a	230.5
" "	3.0	4 c	5 ab	223.7
AVERAGE		10.4	4.4	296.5
C.V.		36	54	28
$LSD_{.05}$		5.4	2.8	n.s.

[1] average of 4 replicates

[2] numbers in the same column followed by the same letter do not differ significantly ($P < .05$) according to the LSD test

CROP INJURY : All pendimethalin treatments caused crop thinning, EWRC scoring for all pendimethalin treatments = 4, for all other treatments = 1

Table 23. Control of Bromus pectinatus Thunb. and yield of rapeseed using oxadiazon, 1983 [1].

TREATMENT	HERBICIDE RATE (kg ai/ha)	RAPESEED COUNTS (plants/m^2)	B. pectinatus COUNTS (plants/m^2)	SEED YIELD (g/m^2)
untreated	-	19 a [2]	16	272.8
pre oxadiazon	0.48	10 b	13	278.1
" "	0.72	11 b	14	323.2
" "	0.96	7 b	12	332.1
" "	1.20	10 b	12	310.5
" "	1.44	9 b	11	355.3
AVERAGE		11	13	312.0
C.V.		44	20	20
$LSD_{.05}$		7.3	n.s.	n.s.

[1] average of 4 replicates

[2] numbers in the same column followed by the same letter do not differ significantly ($P < .05$) according to the LSD test

CROP INJURY : All oxadiazon treatments caused crop thinning, EWRC scoring for the oxadiazon treatments = 4

Table 24. Control of *Bromus pectinatus* Thunb. and yield of rapeseed using EPTC, 1983[1].

TREATMENT	HERBICIDE RATE (kg ai/ha)	RAPESEED COUNTS (plants/m^2)	*B. pectinatus* COUNTS (plants/m^2)	SEED YIELD (g/m^2)
untreated	-	30	12 a	287.1
ppi EPTC	1.5	24	7 b	320.5
" "	2.3	28	4 bc	268.4
" "	3.1	26	3 c	276.1
" "	3.9	27	4 bc	326.8
" "	4.6	25	3 c	305.4
AVERAGE		26.7	5.5	297.4
C.V.		20	21	21
$LSD_{.05}$		n.s.	3.7	n.s.

[1] average of 4 replicates

[2] numbers in the same column followed by the same letter do not differ significantly by the LSD test

CROP INJURY : no crop injury was observed, EWRC scoring for all treatments = 1

Table 25. Pot grown Bromus pectinatus Thunb. survival after glyphosate application.

APPLICATION RATE (kg ai/ha)	GROWTH STAGE OF B. pectinatus AT SPRAYING	PERCENTAGE SURVIVAL[1]
0.178	3 - leaf	3.3 b[2]
"	mid - tillering	32.0 a
"	start of panicle emergence	42.0 a
0.534	3 - leaf	0 b
"	mid - tillering	0 b
"	start of panicle emergence	0 b
1.068	3 - leaf	0 b
"	mid - tillering	0 b
"	start of panicle emergence	0 b
AVERAGE		8.53
C.V.		90
$LSD_{.05}$		11.2

[1] average of 4 replicates

[2] numbers followed by the same letter do not differ significantly ($P < .05$) according to the LSD test

However, when glyphosate was applied at a 0.178 kg/ha rate, efficacy was growth stage dependent, being more effective when applied to the 3 leaf stage, then when applied at mid-tillering, or panicle emergence stages.

Some *B. pectinatus* plants survived the sub-optimal rate of glyphosate (0.178 kg/ha). The plants which survived were often malformed. As the treated plants grew, some developed a purplish tinge, new leaves often had whitish margins and tips, many were severely stunted with culm thickening and distorted panicles, some panicles had infertile spikelets. These symptoms are typical of glyphosate injury (Grossbard and Atkinson, 1983).

Glyphosate rates of 2.25 kg/ha have been used to kill *B. japonicus*, *B. secalinus* and *B. tectorum* (Runyan and Peeper, 1978b). *B. inermis* has been controlled with glyphosate at a 1.12 kg/ha rate (Waller and Schmidt, 1983) and *B. mollis* with 0.4 kg/ha (Hughes, 1976).

Of the herbicides evaluated, in both wheat and rapeseed during 1982 and 1983, only glyphosate, fluazifop-butyl and fenthiaprop-ethyl can be considered to give excellent *B. pectinatus* control. Glyphosate cannot be used post crop emergence and fluazifop-butyl and fenthiaprop-ethyl cannot be used in wheat and barley. Other herbicides tested, such as triallate, metribuzin, pendimethalin, trifluralin and chlorsulfuron, provided limited control of *B. pectinatus*, at least in one year, but limited control is not satisfactory. Leaving some *B. pectinatus* plants to compete with the crop will reduce yields and perpetuate the problem to the next cropping season. Also, when the entire population is not controlled, the risk of developing herbicide resistant biotypes increases.

The herbicides that provided some control in these trials were

growth stage dependent and/or were soil active. Growth stage dependent herbicides would require several applications in a crop to control *B. pectinatus* with its discontinuous germination. Soil active herbicides are partially dependent on environment, and efficacy is often dependent on variable soil moisture conditions. Consistancy of efficacy is required of a herbicide for farmer acceptance.

Based on the excellent efficacy of fluazifop-butyl and fenthiaprop-ethyl it is suggested that a crop rotation, including rapeseed, in which an application of either fluazifop-butyl or fenthiaprop-ethyl is included will be satisfactory towards controlling *B. pectinatus*.

GENERAL DISCUSSION

In Kenya, the use of herbicides and the practice of continuous cereal monoculture, in the natural habitat of *Bromus pectinatus* Thunb., has enabled *B. pectinatus* to change from a weed, found mainly in headlands, to a weed found in cereals. Herbicidal control of wild oats (*Avena fatua*) and ryegrass (*Lolium* species) in Kenyan cereals, grown in the highlands, opened a niche which was rapidly filled with *B. pectinatus* (Stobbe, 1983). *B. pectinatus* not only moved into this niche but has, in some fields, become the dominant weed species, even when wild oats and ryegrass are not controlled. *B. pectinatus* resistance to many herbicides (Chapter 6) and continuous cereal monoculture have facilitated a long term selection pressure which has changed *B. pectinatus* from a ruderal (growing among rubbish) to an agrestal (growing in fields or cultivated land).

Many of the characteristics of an ideal weed, as outlined by Baker (1974), can be found in *B. pectinatus*.

In *B. pectinatus* germination requirements are fulfilled in many environments. Germination occurred in the soil to depths of 8 cm (Chapter 3). Germination also occurred in soil pH ranging from 3.85 to 8.13, and at temperatures ranging from 3 to 28 C (Chapter 3).

Discontinuous germination and longevity of seed are characteristic of *B. pectinatus*. In *B. pectinatus* there is an innate dormancy which can persist up to 8 months (Chapter 4) unless broken by scarification (Chapter 3) or hull removal (Chapters 3 and 4). Seeds can also germinate after storage for two years (Chapter 3).

B. pectinatus has rapid growth through the vegetative phase. In

one experiment it took 61 to 145 days for the first *B. pectinatus* panicle to emerge with the overall average being 104 days (Chapter 2). In the replacement series experiments (Chapter 5) *B. pectinatus* matured at least a month before either the wheat or rapeseed. *B. pectinatus* is an annual which competes with the crop early in the season but is generally desiccated by harvest.

B. pectinatus produces seed over a long period, but not necessarily for as long as the growing conditions would permit. Once *B. pectinatus* has reached the reproductive phase panicles begin to emerge and culms may continue to be produced. Seed is shed continuously from the time the first panicle on the earliest plant matures, till the plant is killed by cultivation or desiccation (Chapter 4).

B. pectinatus is self-compatible, but it is not known whether it is completely autogamous. Hulbert (1955) believes self-pollination is the rule for most annual bromegrasses. *B. mollis*, an allied species of *B. pectinatus* (Chapter 1) is not completely autogamous. In *B. mollis*, "adjustments" in the level of outcrossing will occur to optimize occupations of diverse habitats (Allard, 1965).

Under favorable conditions *B. pectinatus* has a very high seed output. One plant grown in soil from Mau Narok, in the shadehouse, produced 611 spikelets (on average) (Table 6). With an average of 10 seeds per spikelet, an average of 6,100 seeds were produced on these plants.

B. pectinatus is very tolerant and plastic, producing seeds over a wide range of environmental conditions. *B. pectinatus* occurs in East Africa at altitudes between 2,200 and 3,000 m (Clayton, 1971) but has also been observed at altitudes as low as 1,850 m. *B. pectinatus* grew

and produced seed on soils ranging in pH from 4.8 to 7.6 (Chapter 1). Continuous emergence throughout the varied conditions of the 1983 growing season (Chapter 4) also indicates the plasticity of *B. pectinatus* environmental requirements.

Dispersal of *B. pectinatus* can occur over both short and long distances. The morphological characteristics of *B. pectinatus* facilitate its dispersal by man. The fibrous open nodding panicle (Chapter 1) with the basil seeds of spikelets still attached (Chapter 4) tangle on to harvesting equipment. With the increasing use of custom harvesting, mainly as a result of the decline of farm size (Mulamula, 1983), there is great opportunity for seed spread on equipment. The use of "gunny bags" for grain storage and transport also provides opportunity for seed spread. The simple straight awn, and pectinate hairs of the seeds (Chapter 1) enable *B. pectinatus* seed to cling to the bags and makes obtaining clean grain difficult.

B. pectinatus has many of the characteristics necessary to be a weed of Kenyan cereals. These weedy characteristics, the result of preadaption alone, combined with the fortuitous opening of a niche to which *B. pectinatus* could move, have assisted *B. pectinatus* to become a major weed in Kenyan wheat and barley.

The weed *B. pectinatus* is a largely self-pollinated species which is found over a range of environments in geographically isolated locals. Under such circumstances it might be expected that local subspecies might arise. A distinct subspecies of *B. pectinatus* based on growth response to different environments, was not detected in *B. pectinatus* plants from three locations in Kenya (Chapter 2). The possibility of subspecies of *B. pectinatus* existing on a biochemical basis was not

investigated, but should not be ignored. It is possible that the difference in herbicide response in the 1982 and 1983 wheat trials (Chapter 6) was not due to leaf stage or environmental differences, but instead was due to a change in field location and a different *B. pectinatus* population. Thai *et al.* (1985) have found that populations of wild oats treated with recurrent exposure to triallate were more tolerant of triallate than historically unexposed populations.

Interference experiments have many disadvantages. In additive schemes, the proportional composition and density of the mixture change over time (Harper, 1977). Thus, the yield loss equation of $y = 533.837 - 80.538 \sqrt{X}$ (Chapter 5) is specific for *B. pectinatus* counts late in the season, rather than early, and, therefore, cannot be used for predicting yield losses due to *B. pectinatus* infestation. In the replacement series experiments the results obtained were specific to that plant density and arrangement (Chapter 5). Any major inferences about the nature of competition between *B. pectinatus* and wheat or rapeseed should not be based on the results of these individual experiments. Inouye and Schaffer (1981) emphasize that inferences about competition between species should not be drawn from any single replacement series experiment.

Herbicide efficacy against *B. pectinatus* may be, in part, crop cultivar dependent. In Kenya, triallate is recommended for control of *B. pectinatus* in barley, but not in wheat (Chapter 6). This distinction has arisen because generally barley is more competitive than wheat (Dew, 1974; Pavlechencho and Harrington, 1934) and barley matures later than does wheat (Chapter 2). However, in Kenya, with wheat (cv. Kenya Paa) and barley (cv. Tumaini), the barley matured earlier and was less

competitive than wheat (Chapter 5). With these particular cultivars triallate might have given more satisfactory control in the wheat than in the barley. Some evidence towards this possibility is also given by the 1982 triallate trial in wheat (cv. Kenya Paa) being partially effective while the 1983 triallate trial in wheat (cv. Tembo) was ineffective (Chapter 6).

Biological control of *B. pectinatus* using a plant pathogen may be feasible. In the field, especially at lower altitudes, *B. pectinatus* will often become covered in the bright yellow pustules of crown rust (*Puccinia coronata*) late in the growing season (Chapter 5). The weediness of *B. pectinatus* would be reduced with infection by crown rust. Early infection of *B. pectinatus* with a crown rust pathogen may be useful towards suppressing *B. pectinatus*.

Biological control by animals is unlikely to be successful. Cattle will graze on the vegetative shoots of *B. pectinatus*, but like the rats (Chapter 5), they prefer wheat over *B. pectinatus*. The leaves and leaf sheaths of *B. pectinatus* plants are often pubescent (Chapter 1) which would tend to make them less palatable than other less-pubescent grasses. Birds ignored *B. pectinatus* seed in favor of the wheat (Chapter 5). The avoidance of *B. pectinatus* by birds can be explained in that *B. pectinatus* seeds are relatively small, awned, and have a tightly-attached pectinate lemma and palea (Chapter 1). These seed characteristics make *B. pectinatus* seed less palatable than seeds from some other grasses.

The potential success of certain tillage practices can be ascertained from the germination and emergence requirements of *B. pectinatus*. Light inhibits germination of *B. pectinatus* (Chapter 3).

Tillage practices which encourage *B. pectinatus* to leave seed on the soil surface exposed to light (such as "zero-tillage") might reduce the *B. pectinatus* infestation in succeeding years. However, greater success would likely be achieved using tillage practices which bury the *B. pectinatus* seed to a depth of 8 cm or more under the soil. The 8 cm depth is too deep for emergence of *B. pectinatus* (Chapter 3). A moldboard plowing 18 cm deep, followed by discing, to 8 cm, was found to reduce field infestations of *B. secalinus* (Runyan and Peeper, 1979b). Complications may arise from deep burial of seed. A dormancy of 8 months (Chapter 4) and the ability to remain viable in storage for 2 years (Chapter 3) could be a problem for deep burial. Should the deeply buried *B. pectinatus* seed be brought to the surface as a result of subsequent tillage operations the previously dormant *B. pectinatus* seeds could reinfest the field.

Crop rotations, based on crop competition, are one of the most economical methods of weed suppression. Crop rotations also increase the range of herbicides that may be applied against a particular weed problem. Rapeseed dry matter yields were not affected by *B. pectinatus* competition in the replacement series mixtures (Chapter 5) or in the weedy checks of the herbicide trials (Chapter 6). Under rapeseed competition in the replacement series mixture, *B. pectinatus* produced fewer culms (Chapter 5) and was made less competitive. Excellent control of 4 leaf stage *B. pectinatus* was achieved with fluazifop-butyl at 0.25 kg/ha and fenthiaprop-ethyl at 0.125 kg/ha (Chapter 6). These two herbicides can safely be used in rapeseed but not in wheat or barley. Rapeseed, in crop rotation with wheat and barley, will enable cereal growers to achieve *B. pectinatus* suppression because of the superior

competitiveness of rapeseed, and the superior efficacy of fluazifop-butyl and fenthiaprop-ethyl against *B. pectinatus*.

SUMMARY AND CONCLUSIONS

Bromus pectinatus Thunb. can be found in countries all along the east side of the African continent. However, it has been reported as a major weed only in Turkey and Kenya. *B. pectinatus* is naturally adapted to the highlands which coincide with the majority of the traditional wheat and barley production areas in Kenya. The preadaption of *B. pectinatus* to the Kenyan highlands, combined with the opening of a niche in wheat and barley crops (brought about with herbicidal control of other weeds) facilitated movement of *B. pectinatus* into some fields. Once in a field, the use of custom combines and gunny sacs facilitated dispersal of *B. pectinatus* to other fields. Once populations are allowed to build up in a field a yield loss equation indicates that an infestation of, as little as, 11 *B. pectinatus* plants/m^2 can reduce wheat yields by 50%.

Soil pH is not a significant factor in determining the distribution of *B. pectinatus* in Kenya. However, soil pH may be important in determining the "weediness" of *B. pectinatus*. *B. pectinatus* germinated and grew in soils over a pH range of 4.8 to 7.15. *B. pectinatus* plant height, days to first panicle emergence, and number of spikelets/culm were not influenced by soil pH, whereas, the number of culms/plant were. *B. pectinatus* grew best on a soil of pH 6.55 and when soil pH influenced germination there was an optimum pH for germination in the 5.5 to 6.0 range. A soil pH of approximately 3 is unable to support germination or growth of *B. pectinatus*. Soil liming of slightly acid soils may reduce the relative competitiveness of *B. pectinatus*.

Distribution of *B. pectinatus* in Kenya is determined mainly by

temperature and moisture requirements. Preheating or prechilling treatment of *B. pectinatus* failed to break its dormancy. Laboratory germination of *B. pectinatus* seed occurred at temperatures as low as 3 C and as high as 28 C with an optimum germination temperature of 17 C. Field emergence of *B. pectinatus* is controlled by an innate dormancy to take advantage of the distinct seasonality of precipitation in Kenya. Seeds remain dormant for as long as 8 months during the dry season and begin germination with the onset of the long rains.

Satisfactory chemical control of *B. pectinatus* in a system of cereal monoculture was not possible. Consistant effective control of *B. pectinatus* in wheat was not achieved. However, in rapeseed, fluazifop-butyl at 0.25 kg/ha and fenthiaprop-ethyl at 0.12 kg/ha have demonstrated excellent efficacy against *B. pectinatus*.

Cultural control of *B. pectinatus* has some potential. Plowing so that the *B. pectinatus* seed is buried 8 cm or deeper in the soil will minimize seed emergence. In contrast, zero-tillage systems which leave *B. pectinatus* seed on the soil surface may also be advantageous towards suppressing *B. pectinatus*. Light is inhibitory to germination of *B. pectinatus* seed. Seeds on the soil surface would be less subject to degradation and it has been shown that removing the lemma and palea, pricking the lemma, or removing the rachilla segment will increase germination of dormant *B. pectinatus* seed.

The most effective post-emergence herbicides for controlling *B. pectinatus* will be those which would be effective when applied during the driest period of the long rains, usually late June. *B. pectinatus* will emerge in the field throughout the growing season, but the majority of emergence occurs soon after the onset of the long rains. Controlling

the first flush would substantially reduce *B. pectinatus* infestation, and crop competition should be adequate to deal with subsequent emerging *B. pectinatus* plants.

To minimize the risk of yield losses due to *B. pectinatus* it is important that the crop be sown soon after final seedbed preparation. When sowing of wheat and barley into a *B. pectinatus* site was delayed yield reductions, correlated with the length of dalay, occurred. A delay gives *B. pectinatus* an increased shoot size at crop emergence, and the larger size increases the interference potential of *B. pectinatus*. *B. pectinatus* interfers with wheat mainly above ground.

Rapeseed was found to be an effective smother crop against *B. pectinatus*. Rapeseed suppressed *B. pectinatus* growth with negligible effect on its own growth. Interference by rapeseed, or wheat, on *B. pectinatus* delayed the relative maturity of *B. pectinatus*.

The superior competitiveness of rapeseed, and the superior efficacy of fluazifop-butyl and fenthiaprop-ethyl, suggests that suppression of *B. pectinatus* can be achieved easier in rapeseed than in wheat. Control of *B. pectinatus* in wheat, requires that a crop rotation with rapeseed be used.

SUGGESTIONS FOR FURTHER WORK

Further herbicide trials need to be conducted. Herbicides yet untested, but found effective against allied *Bromus* sp., should be evaluated for efficacy against *B. pectinatus* (Table 26). Also, the minimum economic rate and range of effective application stages, has to be determined for the herbicides found effective against *B. pectinatus*. Herbicide evaluations may have to be crop cultivar specific.

An evaluation of the long-term effects of tillage practices, such as deep plowing and zero-tillage on reducing field infestation by *B. pectinatus* would be of value. Herbicides are not always available and tillage management may be one of the few options available to growers for controlling *B. pectinatus*.

An investigation of the importance of oat crown rust in suppressing the weediness of *B. pectinatus* should be conducted. The development of a biological control agent, effective against *B. pectinatus*, and manufactured in Kenya, could arise from such research.

Further studies into the effects of amending slightly acid soil, with lime, on reducing the weedyness of *B. pectinatus* should be conducted. Lime is a local product of Kenya and the addition of lime to a soil, making it slightly alkaline, may improve crop growth, while inhibiting growth of *B. pectinatus*.

Further work investigating the duration of dormancy in *B. pectinatus* in the field is needed. The knowledge of dormancy duration is useful in determining how long control practices must be carried out in order to completely eliminate *B. pectinatus* from a field.

To better understand the field emergence pattern of *B. pectinatus*

Table 26. Herbicides effective against Bromus sp. closely allied to Bromus pectinatus Thunb.

HERBICIDE	BROMUS SP. CONTROLLED	REFERENCES
Urea Herbicides		
CHLOROXURON	B. secalinus	Talbert & Vaile,1969
METHABENZIATHIAZURON	B. mollis	Cooper,1982
LINURON	B. mollis	Cooper,1982
MONURON	B. commutatus	Finnerty & Klingman,1962
	B. secalinus	Finnerty & Klingman,1962
Cellulose Biosynthesis Inhibitor Herbicides		
DICHLOBENIL	B. mollis	Bouchet & DeGournay,1965
CHLORTHIAMID	B. mollis	Bouchet & DeGournay,1965
S - triazine Herbicides		
SIMAZINE	B. secalinus	Uhlig,1964
PROMETYRNE	B. mollis	Anonymous,1968
Antimitotic Herbicides		
PROPYZAMIDE	B. mollis	Hughes,1976
PRONAMIDE	B. mollis	Allen et al,1972
Carbamate Herbicides		
CARBETAMIDE	B. mollis	Allen et al,1972 Hughes,1976 Anonymous,1978
ASULAM	B. mollis	Hughes,1976 Soper & Hutchison,1976
CHLORPROPHAM	B. mollis	Bouchet & DeGournay,1965
	B. secalinus	Freeman,1960 Talbert & Vaile,1969
	B. commutatus	Freeman,1960
Aliphatic-Carboxilic Herbicides		
DALAPON	B. mollis	Warren,1968 Hughes,1976 Cooper,1982
	B. secalinus	Kurth,1964 Uhlig,1963
TCA	B. mollis	Cooper,1982 Anonymous,1968
	B. secalinus	Finnerty & Klingman,1962 Kurth,1964
	B. commutatus	Finnerty & Klingman,1962
Auxin Inhibitor Herbicides		
DICLOFOP-METHYL	B. secalinus	Mathis et al,1976
Carotinoid Biosynthesis Herbicide		
AMITROLE	B. secalinus	Uhlig,1963
	B. mollis	Evans et al,1963
Nucleic Acid and Protein Biosynthesis Inhibitor Herbicide		
ENDOTHAL	B. commutatus	Finnerty & Klingman,1962 Freeman,1960
	B. secalinus	Finnerty & Klingman,1962 Freeman,1960
Unclassified Herbicides		
ETHOFUMESATE	B. mollis	O'Connor et al,1975 Hughes,1976 Griffiths et al,1978 Goldsworthy & Drummond,1981 Cooper,1982
TCP	B. secalinus	Kurth,1964
DNAP	B. secalinus	Finnerty & Klingman,1962
	B. commutatus	Finnerty & Klingman,1962
DIPHENAMIDE	B. secalinus	Eli Lilly & Co. Ltd.,1961

further studies on the influence of seed age on the effects of soil pH, light and temperature, on germination, are required.

B. pectinatus has only recently become a major weed and it would be useful to compare the biology of *B. pectinatus*, in Kenya, which are growing in historically ruderal locations with those growing as weeds. Such a comparison might help to explain whether the recent weediness of *B. pectinatus* is only the result of fortuitous preadaptation and a recently opened niche, or whether *B. pectinatus* has evolved a "weedy" subspecies which has aided crop infestation.

Further work comparing the biology of *B. pectinatus* plants from Kenya with *B. pectinatus* from other countries would be of value. Such a study would determine whether there is a "weedy" subspecies of *B. pectinatus* present in Kenya that might necessitate phytosanitary control of seed exports.

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Appendix

Appendix 1. : Precipitation and temperature recorded at the National Plant Breeding Station, Njoro, Kenya, February 1982 to February 1984

Date	February, 1982 Rain mm	February, 1982 Temperature Min.(C)Max.	March, 1982 Rain mm	March, 1982 Temperature Min.(C)Max.	April, 1982 Rain mm	April, 1982 Temperature Min.(C)Max.	May, 1982 Rain mm	May, 1982 Temperature Min.(C)Max.	June, 1982 Rain mm	June, 1982 Temperature Min.(C)Max.
1		10.4 - 25.3		8.2 - 27.8		13.0 - 24.0	N.V.*	N.V. - N.V.	14.7	10.0 - 22.8
2		8.0 - 26.5		9.6 - 28.3	18.3	12.0 - 20.9	19.4	10.2 - 25.0		9.3 - 22.0
3		10.4 - 26.5		10.5 - 28.0		12.5 - 19.3	17.0	11.0 - 23.8	4.5	7.9 - 22.4
4		9.6 - 26.8		9.5 - 28.0	1.0	12.5 - 25.0	12.5	9.0 - 23.2		9.1 - 22.8
5		9.6 - 26.5		8.7 - 28.0	0.3	11.0 - 25.0		12.0 - 22.0		8.2 - 22.3
6		8.5 - 26.2	0.4	10.5 - 27.0		10.0 - 24.5	3.0	13.2 - 21.5		8.0 - 23.0
7		8.4 - 27.7		9.0 - 26.3		10.5 - 26.3		8.8 - 22.2		8.2 - 22.5
8		10.3 - 26.8	0.8	8.0 - 27.0	8.3	12.5 - 26.0		10.2 - 22.4		8.9 - 22.5
9		10.1 - 27.3		9.0 - 27.3	3.0	9.2 - 22.8		10.8 - 22.6		8.2 - 22.7
10	0.5	10.6 - 25.5		8.0 - 26.8		10.2 - 24.6		9.2 - 21.6		9.2 - 23.2
11		9.3 - 26.0		8.0 - 26.7	0.5	9.8 - 23.2	13.6	13.4 - 22.8	0.5	7.8 - 23.0
12		9.3 - 26.1		6.5 - 27.6	4.2	10.4 - 25.4	3.0	10.2 - 22.0		7.5 - 23.6
13		8.8 - 27.3		9.0 - 26.5		13.8 - 24.9	6.5	10.9 - 22.2		8.2 - 22.5
14		12.3 - 27.3		7.8 - 27.3		11.9 - 25.2		9.6 - 22.2	0.5	8.8 - 22.6
15	5.0	9.3 - 26.5		8.8 - 27.2	0.6	11.3 - 24.3		10.2 - 22.2	0.3	7.0 - 27.1
16	7.4	9.9 - 24.9		9.3 - 26.2	11.3	13.1 - 23.5		8.3 - 22.3		10.1 - 22.2
17	5.4	9.8 - 25.0		7.5 - 27.0	11.5	13.5 - 22.9	4.7	10.3 - 23.4	4.9	10.2 - 22.5
18	2.7	9.0 - 26.0		8.3 - 27.3	2.3	9.5 - 21.6	22.9	13.0 - 22.2	3.7	11.6 - 22.5
19		8.5 - 25.4		11.0 - 28.4	1.1	11.2 - 24.6	3.7	11.5 - 21.5		10.6 - 21.9
20		8.0 - 26.5		11.3 - 27.8	11.4	10.6 - 24.0	5.8	10.3 - 21.8		8.0 - 22.8
21		8.3 - 25.6		11.4 - 27.6	4.0	9.9 - 23.8	T	10.5 - 21.6	0.5	12.3 - 22.5
22		8.5 - 26.4	2.3	8.0 - 27.0	1.8	11.9 - 23.4	3.2	10.0 - 21.9	0.8	11.7 - 22.4
23		8.6 - 26.3		7.9 - 28.0		10.2 - 24.1	7.0	12.8 - 23.1		11.8 - 21.8
24		8.3 - 25.8		8.5 - 28.0	2.3	10.1 - 24.4	1.1	9.5 - 20.7	8.0	8.9 - 21.4
25		10.0 - 28.3		8.8 - 28.4	2.3	7.5 - 22.8		9.0 - 22.8	1.3	6.6 - 21.7
26		10.3 - 28.3		7.0 - 28.5	8.6	10.8 - 23.4		10.5 - 23.0		6.9 - 22.4
27		10.5 - 29.2		9.0 - 27.8	11.0	12.2 - 23.5	4.9	12.4 - 23.1		5.0 - 22.0
28		7.6 - 27.8		11.0 - 28.7	32.8	9.9 - 23.3	0.4	9.9 - 22.0		6.8 - 21.0
29			1.4	13.8 - 28.4	3.6	13.4 - 23.4		11.5 - 23.6	0.6	5.7 - 21.4
30				13.0 - 24.5	3.9	11.0 - 24.0	3.1	12.5 - 22.0		5.6 - 21.8
31				13.0 - 27.5			8.0	10.9 - 22.0		
Total	21.0		4.9		144.1		139.8		40.3	
Average		9.4 26.6		9.4 27.5		11.1 23.8		10.7 22.4		8.6 22.5

Appendix 1. continued (page 2)

Date	July, 1982 Rain mm	July, 1982 Temperature Min. (C) Max.	August, 1982 Rain mm	August, 1982 Temperature Min. (C) Max.	September, 1982 Rain mm	September, 1982 Temperature Min. (C) Max.	October, 1982 Rain mm	October, 1982 Temperature Min. (C) Max.	November, 1982 Rain mm	November, 1982 Temperature Min. (C) Max.
1		5.5 - 20.1	16.8	7.8 - 24.3		7.9 - 23.4		6.8 - 22.6	0.5	10.6 - 21.5
2		5.5 - 21.8	36.3	12.0 - 22.6	0.6	7.4 - 23.0		6.5 - 23.1	17.0	13.4 - 21.2
3		8.5 - 23.8	1.0	10.8 - 20.0	0.9	8.2 - 24.3		6.6 - 23.2	8.3	13.5 - 21.4
4		11.0 - 23.0	13.1	8.0 - 20.8	4.2	10.2 - 23.5	0.4	5.2 - 22.8	8.5	9.8 - 21.4
5		6.6 - 22.6	22.8	8.0 - 21.4	0.4	8.5 - 23.5		6.4 - 23.7		10.0 - 22.1
6		6.4 - 21.3	8.6	7.4 - 21.6		7.0 - 23.2		7.8 - 24.4		9.9 - 23.9
7		11.6 - 22.6	3.8	6.8 - 22.3	3.2	7.1 - 23.4	0.3	7.5 - 23.5	1.3	10.3 - 23.3
8	1.4	8.0 - 22.2		7.0 - 21.6		6.0 - 23.0	1.3	7.0 - 24.7		11.6 - 23.4
9	8.3	6.4 - 21.8		6.8 - 22.5		7.2 - 23.3	1.3	7.8 - 23.3		11.0 - 21.3
10		8.4 - 21.8		7.0 - 22.0		7.0 - 23.0		7.3 - 23.6	T	11.6 - 22.3
11		7.0 - 22.0	3.4	8.2 - 21.4	0.4	8.2 - 23.4		8.9 - 23.9	T	9.2 - 23.2
12		8.0 - 23.0	11.3	10.1 - 24.9		6.0 - 22.7	1.0	12.5 - 21.7	12.4	9.6 - 22.0
13		6.5 - 22.7	38.5	11.5 - 22.0		7.0 - 23.6	0.2	7.0 - 21.0		9.0 - 22.2
14		7.1 - 23.2	6.5	10.8 - 20.3		8.1 - 24.6	0.1	11.0 - 24.0		10.0 - 21.6
15		11.4 - 22.7	20.6	11.9 - 18.1	1.0	13.3 - 21.8	0.7	10.5 - 24.4	15.0	11.8 - 21.6
16	6.0	6.3 - 22.8	13.7	12.3 - 19.8	0.2	11.6 - 21.2	0.2	7.4 - 23.4	6.3	10.8 - 20.5
17		10.5 - 22.0	0.3	12.2 - 20.3	2.5	9.3 - 22.7	1.9	13.0 - 21.5		9.8 - 20.8
18		8.5 - 22.0		8.9 - 21.0		7.6 - 23.7	8.5	12.5 - 18.8		12.6 - 21.5
19		5.4 - 23.0		8.8 - 21.2		7.6 - 23.0	37.8	10.5 - 21.3		9.2 - 18.2
20		5.1 - 22.7	12.3	7.4 - 21.4		8.7 - 24.0	12.1	7.3 - 19.9	1.0	11.4 - 20.6
21		5.5 - 23.8		8.0 - 23.1		12.3 - 23.6	3.6	11.3 - 21.3		8.3 - 20.3
22		7.0 - 22.9	0.2	8.0 - 21.6	2.3	8.8 - 22.7	9.3	10.8 - 18.8		9.0 - 22.9
23	2.3	7.8 - 22.8	3.7	9.0 - 22.1	9.7	12.0 - 22.8	1.6	9.8 - 21.8	5.0	8.8 - 22.5
24	7.6	10.8 - 22.6	0.5	9.8 - 21.1	1.3	7.4 - 21.3		8.0 - 21.2	0.6	13.7 - 22.8
25	T	8.3 - 19.3	12.5	7.0 - 21.4	1.9	6.8 - 22.0		9.3 - 19.6	0.5	9.5 - 22.0
26		6.9 - 21.1		7.5 - 21.7		11.3 - 22.0	1.3	8.5 - 22.1	9.5	11.8 - 22.0
27		6.5 - 21.9	1.0	9.4 - 22.5		6.3 - 22.6	T	10.5 - 23.3	13.2	10.2 - 20.6
28		6.2 - 22.6	4.0	6.6 - 21.6		7.5 - 23.3		8.5 - 22.8	3.2	12.5 - 21.4
29	0.4	8.2 - 23.8	16.6	7.1 - 21.6		6.5 - 23.4	0.4	11.1 - 24.0	24.8	8.3 - 18.3
30		7.0 - 24.5	0.4	7.3 - 22.4		8.0 - 23.1	12.0	12.5 - 20.5	7.3	12.1 - 20.3
31	T	8.4 - 24.4		6.9 - 22.5			0.4	13.2 - 22.3		
Total	26.0		247.9		28.6		94.0		134.4	
Average		7.6 22.5		8.7 21.7		8.4 23.1		9.1 22.3		10.6 21.6

Appendix 1. continued (page 3)

Date	December, 1982 Rain mm	December, 1982 Temperature Min.(C)	December, 1982 Max.	January, 1983 Rain mm	January, 1983 Temperature Min.(C)	January, 1983 Max.	February, 1983 Rain mm	February, 1983 Temperature Min.(C)	February, 1983 Max.	March, 1983 Rain mm	March, 1983 Temperature Min.(C)	March, 1983 Max.	April, 1983 Rain mm	April, 1983 Temperature Min.(C)	April, 1983 Max.
1	6.0	13.3	21.5	N.V.	8.3	N.V.		10.5	24.3		10.0	28.0	0.7	10.6	26.6
2	22.1	12.5	21.7		9.3	23.7	0.8	11.0	26.8		8.9	28.0	2.4	10.4	25.3
3	2.6	12.5	21.5		6.0	22.8		14.2	26.3		8.0	27.5		10.5	24.0
4	2.8	12.5	21.5		6.2	23.2		11.7	24.0		10.1	27.0		10.0	28.3
5	1.6	12.8	22.3		8.0	23.5		11.5	25.1	4.7	10.1	27.2		11.0	27.5
6		8.4	21.4	1.7	11.0	23.5		8.0	25.3		10.0	26.4		10.3	27.3
7	1.3	11.5	20.4	14.0	10.0	23.5		7.4	25.8		9.0	27.0		9.5	28.0
8	6.6	11.8	20.6		6.8	22.3		6.9	26.0		9.5	28.4	1.6	10.0	27.5
9	0.2	8.0	21.0		7.6	23.1		7.1	25.8	0.5	10.0	29.0		9.0	22.5
10		7.6	22.0		7.7	22.7		9.5	27.0		10.4	23.6		9.2	25.6
11	1.6	9.5	20.9		7.0	23.3		11.9	27.0		10.1	25.8		10.0	27.0
12		10.9	21.8		5.9	22.6	14.6	10.8	23.8		10.9	29.0	2.7	10.0	27.4
13	6.8	12.3	22.3		8.3	22.3	1.2	10.8	19.7		11.5	28.6		11.0	25.5
14		8.4	20.3		7.0	23.7		11.6	25.3	4.3	11.5	28.0	0.9	11.3	24.5
15		9.0	21.0		8.0	23.3		14.0	25.1		12.3	25.1		10.3	26.1
16		8.0	22.9		9.0	23.3		12.1	23.5		10.0	27.4	T	12.0	27.2
17	2.7	13.5	22.3		9.0	24.0		12.1	25.2		10.5	26.5	1.4	10.8	27.5
18	8.8	11.2	22.1		9.4	25.1	4.2	10.5	25.8		10.8	27.3	7.7	10.4	27.0
19		8.2	22.0		10.9	25.1		12.2	26.5		10.3	27.3		11.0	27.8
20		7.6	21.9	0.5	10.7	25.8	2.0	11.0	25.8		9.5	28.0	2.1	10.9	27.6
21		11.4	23.7		10.5	25.6	3.4	8.8	24.0		9.8	28.4		12.1	26.8
22	3.3	13.2	23.0		11.4	26.4		10.2	26.0		10.0	28.6	0.8	13.2	23.7
23	1.8	9.3	22.8		9.7	25.5		10.4	26.2		11.0	29.0	9.2	12.6	23.3
24		6.5	22.0		11.0	25.0		9.4	26.3		11.9	29.1	15.6	12.4	20.7
25		8.3	22.6		11.8	25.9		9.3	26.4		11.4	28.8	1.2	13.4	21.5
26		9.7	22.7		9.9	25.5		7.0	25.1		11.4	29.4	0.1	12.7	23.5
27		8.8	23.4	8.0	9.5	24.2		9.5	26.7		11.3	29.0	46.2	12.5	25.0
28		9.5	22.4	T	9.2	25.4	1.7	10.5	27.0		12.5	28.6	1.0	12.9	22.0
29		7.0	21.9		7.9	25.5				0.2	15.4	28.3	2.6	12.6	25.3
30		7.0	22.1		8.8	25.3					11.6	27.5	8.5	12.0	22.8
31		6.8	22.2		9.3	26.0				4.0	12.5	27.5			
Total	68.2			24.2			27.9			13.7			104.7		
Average		9.9	28.4		8.9	24.2		10.4	25.4		10.7	27.7		11.1	25.5

Appendix 1. continued (page 4)

Date	May, 1983 Rain mm	May, 1983 Temperature Min.(C)Max.	June, 1983 Rain mm	June, 1983 Temperature Min.(C)Max.	July, 1983 Rain mm	July, 1983 Temperature Min.(C)Max.	August, 1983 Rain mm	August, 1983 Temperature Min.(C)Max.	September, 1983 Rain mm	September, 1983 Temperature Min.(C)Max.
1	15.1	11.0 - 20.5		7.9 - 24.0	N.V.	9.5 - N.V.	2.6	9.5 - 22.5	5.2	9.8 - 22.3
2	18.1	13.5 - 24.5		8.3 - 24.1		7.0 - 21.2	7.3	8.0 - 22.4	4.2	12.5 - 21.0
3	33.5	10.0 - 24.5		8.2 - 22.8	2.0	6.2 - 21.5	T	7.0 - 22.1		11.0 - 22.5
4		9.9 - 24.0	5.3	8.2 - 24.5		6.0 - 22.0		8.0 - 23.2	13.4	9.3 - 21.4
5		10.3 - 23.5	0.4	13.8 - 22.4		5.5 - 21.0	1.8	9.3 - 24.3	6.2	11.7 - 22.3
6	10.8	11.0 - 24.5		12.8 - 24.0		5.0 - 22.0		6.0 - 23.5	30.1	7.9 - 21.9
7		12.0 - 22.0		7.2 - 23.9		7.5 - 23.3		7.0 - 24.3	1.3	6.8 - 21.8
8		10.0 - 24.0		7.7 - 23.6		6.4 - 22.5		9.0 - 24.6		9.3 - 21.2
9		10.6 - 22.5		8.0 - 23.8		6.8 - 23.0		9.0 - 24.0	10.8	8.6 - 21.7
10	14.5	14.0 - 23.1	1.1	8.6 - 25.2		8.0 - 23.7	3.1	9.5 - 20.3	11.0	9.4 - 21.5
11	1.4	10.0 - 24.0		8.5 - 25.3		7.3 - 24.5	6.5	10.5 - 22.5	1.9	8.7 - 20.5
12		12.7 - 22.9		8.3 - 24.2		6.6 - 24.4	2.1	9.5 - 20.5	7.7	7.6 - 21.9
13		12.7 - 22.5	1.1	9.4 - 24.7		7.3 - 23.2	29.0	11.8 - 20.1		7.8 - 23.5
14		9.2 - 22.8		10.0 - 24.0		7.6 - 24.4	0.4	11.4 - 20.0		7.0 - 23.2
15	4.3	8.9 - 22.8	3.9	8.5 - 25.1		9.0 - 26.0		9.2 - 17.0		8.4 - 24.5
16		10.0 - 24.5		8.5 - 24.5	12.4	10.6 - 25.3	1.0	9.5 - 20.0	3.5	9.6 - 24.0
17		10.2 - 25.5		9.4 - 24.0	3.8	12.8 - 24.3	14.0	12.0 - 22.0		8.8 - 23.6
18		9.6 - 24.0		7.9 - 24.0	0.9	12.8 - 22.1	0.8	11.9 - 20.6	2.6	7.8 - 21.8
19		8.5 - 24.2		12.5 - 25.0	0.9	9.3 - 19.5	22.2	12.6 - 16.5		7.3 - 23.4
20	0.6	8.8 - 24.5	2.3	13.0 - 25.5	21.6	8.0 - 18.9	12.0	9.0 - 21.0	2.5	8.0 - 23.0
21	7.2	10.0 - 24.5		11.8 - 23.5	8.1	10.8 - 20.3	8.7	11.6 - 21.3	7.6	11.4 - 22.5
22		9.9 - 23.9	4.1	11.3 - 23.2	1.0	11.8 - 18.8	0.8	9.7 - 21.7	2.5	8.6 - 21.6
23		10.4 - 24.0	3.8	12.0 - 20.9	0.6	12.2 - 22.5	3.8	10.0 - 21.5	6.7	8.0 - 23.2
24	1.1	12.9 - 24.0	T	12.0 - 23.5	2.1	12.5 - 21.0	6.7	11.0 - 22.1	3.4	8.4 - 22.5
25	2.3	10.7 - 24.3		11.5 - 24.2		12.7 - 19.2		8.0 - 20.3	0.7	9.0 - 23.0
26	4.1	10.0 - 24.0	0.2	10.4 - 25.7	12.0	10.5 - 22.4		9.1 - 21.9		11.5 - 24.1
27		8.7 - 24.1	2.6	12.6 - 23.4	4.5	10.7 - 22.1		12.4 - 22.6	5.2	8.6 - 23.5
28		8.9 - 25.0		10.5 - 23.6		9.2 - 23.5	3.0	9.6 - 23.4		9.5 - 23.0
29		10.5 - 25.6	13.1	11.5 - 22.9	0.5	9.8 - 23.0	32.6	8.3 - 22.3	0.6	9.6 - 23.3
30		10.2 - 24.8		10.5 - 20.2		7.8 - 21.8	9.1	9.5 - 22.5		9.5 - 21.1
31		8.1 - 24.1				9.6 - 22.4	0.5	10.8 - 22.6		
Total	113.0		37.9		70.4		168.0		127.1	
Average		10.4 23.8		10.0 23.9		8.9 22.3		9.7 21.7		9.1 22.5

Appendix 1. continued (page 5)

Date	October, 1983 Rain mm	October, 1983 Temperature Min.(C)Max.	November, 1983 Rain mm	November, 1983 Temperature Min.(C)Max.	December, 1983 Rain mm	December, 1983 Temperature Min.(C)Max.	January, 1984 Rain mm	January, 1984 Temperature Min.(C)Max.	February, 1984 Rain mm	February, 1984 Temperature Min.(C)Max.
1	1.8	9.3 - 23.5	4.3	10.0 - 21.7	2.8	6.5 - 22.8		9.0 - 23.1	0.8	8.1 - 24.5
2		8.7 - 22.6	7.9	10.5 - 21.3		7.8 - 23.0		8.0 - 23.6		8.4 - 24.5
3		11.0 - 24.5	6.2	9.0 - 22.1	5.5	6.3 - 22.9		8.9 - 24.0		8.8 - 24.5
4	11.6	12.6 - 23.5		8.9 - 19.5		6.6 - 23.0		8.4 - 23.5	2.2	8.6 - 25.5
5		12.9 - 23.0	6.0	9.0 - 21.5	1.7	8.4 - 22.3		7.0 - 23.4		7.5 - 24.9
6	0.2	13.3 - 22.9	27.1	10.0 - 23.2	24.2	9.2 - 21.1		5.0 - 23.1		7.6 - 26.0
7	8.0	12.5 - 21.5	9.1	11.0 - 22.5		7.0 - 20.5		5.8 - 22.3		8.6 - 25.5
8	1.3	12.4 - 20.4	6.4	9.0 - 22.4	4.8	9.4 - 17.6		6.6 - 23.0		9.0 - 21.5
9	2.6	12.4 - 21.3		9.0 - 22.1	5.2	7.5 - 21.4	0.3	11.0 - 22.9		9.5 - 26.5
10	3.5	12.0 - 20.8		9.0 - 23.0	4.3	10.0 - 20.4		9.2 - 23.3		6.8 - 26.7
11	6.3	10.9 - 21.5		9.0 - 24.2		10.2 - 19.0		10.3 - 23.2		7.1 - 26.2
12	5.2	10.7 - 21.1		8.7 - 23.7		8.5 - 22.5		9.9 - 24.5		7.8 - 25.7
13	T	9.0 - 21.5		8.5 - 23.7		8.0 - 24.0		8.2 - 23.8		7.2 - 26.2
14	2.9	10.0 - 22.4	1.6	10.1 - 23.6		7.4 - 23.5		7.7 - 23.8		6.6 - 25.7
15	6.9	11.4 - 22.7	1.8	9.0 - 23.5		8.4 - 23.5	0.2	8.0 - 23.7		8.0 - 26.5
16	1.1	13.0 - 22.8	0.1	9.1 - 23.8		7.5 - 23.0		8.7 - 24.1		8.9 - 27.4
17		8.2 - 23.5		9.5 - 23.7		7.5 - 22.4		9.2 - 24.0		9.0 - 27.3
18		8.5 - 23.0		10.5 - 22.7		8.9 - 24.4		8.0 - 24.5		8.1 - 27.0
19		9.3 - 23.6	7.0	10.6 - 21.4	10.1	12.3 - 24.3		7.8 - 24.4		5.0 - 26.3
20	3.0	8.4 - 22.3	3.0	13.0 - 21.4	0.3	13.2 - 22.4		8.2 - 24.2		5.7 - 25.0
21	0.5	10.0 - 23.0		9.5 - 21.6	0.2	11.5 - 22.9		8.2 - 24.0		8.2 - 26.0
22		11.8 - 22.8		8.1 - 22.4		10.5 - 21.9		7.9 - 24.6		8.6 - 27.0
23		10.9 - 22.8		10.1 - 22.6	1.2	13.0 - 23.0		9.1 - 24.5		7.0 - 26.2
24		7.5 - 21.3		8.4 - 23.3	44.5	12.0 - 21.0		8.4 - 24.5		7.0 - 26.2
25	2.1	9.0 - 21.3		8.0 - 23.4	13.4	11.1 - 20.5		9.5 - 24.5		8.3 - 26.9
26		7.3 - 22.3	1.7	9.9 - 22.5	2.7	10.0 - 19.2		8.5 - 24.6		8.8 - 27.2
27		8.3 - 22.5		7.8 - 22.5		11.1 - 20.7		8.3 - 23.8	T	9.1 - 25.9
28	1.1	7.4 - 22.7	1.0	8.8 - 23.3		13.0 - 21.5		8.0 - 25.4		9.5 - 26.6
29		7.3 - 22.0		9.0 - 22.6		8.5 - 21.5		8.1 - 26.4	11.9	9.5 - 26.1
30		9.2 - 22.0	T	7.7 - 21.5		9.5 - 22.5		9.4 - 26.7		
31	1.7	10.4 - 22.7				9.8 - 22.5		10.7 - 25.3		
Total	59.8		83.2		120.9		0.5		14.9	
Average		10.2 22.4		9.4 22.6		9.4 22.0		8.4 24.1		8.0 25.9

* N.V. = No Value, no data available