MANAGEMENT OF MIXED ANNUAL BLUEGRASS AND CREEPING BENTGRASS STANDS

BY

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ABSTRACT

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Field studies were conducted at the Hancock Turfgrass Research Center East Lansing, Michigan to determine the effects of nitrogen, potassium, and clipping removal on annual bluegrass and creeping bentgrass interference, to examine nitrogen and cultivation effects on thatch accumulation and the invasion of other grasses into monostands, to determine seeding rates, cultivation practices, and chemical treatments which increase the establishment of creeping bentgrass overseeded into annual bluegrass, and to compare minirhizotron root counts with rootlength densities (RLD) from core sampling data in turf. The soil type was an Owosso-Marlette sandy loam complex (fine-loamy, mixed, mesic, Typic, Glossoboric Hapludalfs). Nitrogen was the only factor which influenced creeping bentgrass spread into annual bluegrass. Treatment with glyphosate + ethofumesate, vertical mowing and seeding at 195 kg ha^{-1} resulted in greatest establishment of overseeded creeping bentgrass. Vertical mowing and core cultivation reduced thatch in creeping bentgrass. Vertical mowing also resulted in the greatest

invasion of annual bluegrass into creeping bentgrass. Minirhizotron root counts did not correlate well with RLD from core samples, but did provide an excellent method for comparing root growth over time.

DEDICATION

To my deceased Father who taught me to work hard and to be patient, to my dear Mother who has demonstrated the virtues of perseverance and love, and to my new wife Julie who´s understanding and motivation helped me get this thesis finished.

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Introduction

Annual bluegrass is often a major component of highly managed turfgrass areas and is found on many golf course fairways in the northeast United States (7,43). Annual bluegrass can be considered a desirable species which produces a fine-textured, dense turf; tolerates frequent mowing; grows under compacted and moist soil conditions; and has moderate shade tolerance when cultural and management practices are implemented to ensure its survival. Annual bluegrass also has several undesirable characteristics including poor high and low temperature tolerance, poor drought tolerance, profuse seedhead formation at all mowing heights and at any time during the growing season, and susceptibility to numerous diseases. Because of these undesirable characterstics annual bluegrass is considered a weed, and cultural and management practices are often implemented for its removal (4,24,39). The occurrence of annual bluegrass is the result of its ability to grow and survive conditions which are unfavorable, damaging, and weakening to other grasses (39,44).

Annual bluegrass exists as an annual biotype, *Poa annua* var. *annua* (L.) Timm., which is a true winter annual characterized by upright bunch-type growth habit and an ability to produce copious amounts of seed which possess a dormancy mechanism (3,4,23,25,40). Annual bluegrass also exists as a more prostrate perennial biotype, *Poa annua* var. *reptans* Hausskn. (Timm.), which is characterized by a branched, weakly stoloniferous growth habit that produces fewer seeds with no dormancy mechanism (3,4,40). The annual biotype characteristically has a less extensive root system while the perennial has a stronger, more fibrous root system (25).

Youngner (44) reported that annual bluegrass will not persist unless the periods between irrigations are short and that persistently wet soils favor annual bluegrass. This was confirmed by Gibeault (23) who found that the type of annual bluegrass present correlated to the amount of water applied. If an area was wet or was irrigated frequently the perennial type was found. However, if the area was dry or irrigated infrequently the annual type was found. Gibeault and Goetze (25) found throughout Oregon and western Washington that the annual type was found in unirrigated rough areas of golf courses. The annual type being able to survive the times of drought by producing seed with a dormancy mechanism which germinated in the fall. The perennial type of annual bluegrass was found to exist on golf greens which were watered frequently and syringed during periods of moisture stress (25). In the cool, humid regions like Michigan, the perennial type is commonly found, while the annual type becomes more prevalent in the southern regions of the United States (2).

There are many reports of annual bluegrasses ability to produce copious amounts of seed (3,24,31,39,40). Annual bluegrass can produce viable seed even when the panicles have been removed from the plant soon after pollination. Research indicates that 1% of the seeds germinated from panicles removed the same day as anthesis (30). It was also determined that maximum annual bluegrass germination (93%) occurred when panicles were allowed to remain on the plant for 16 days or longer. The ability of annual bluegrass to produce abundant, mature seed soon after anthesis helps explain why annual bluegrass is such an aggressive weed.

Annual bluegrass seed can be spread by the wind and by adhering to equipment and shoes when the turf is moist (39). Germination of annual bluegrass seed is increased by light (4). Gibeault (24) reported that close mowing, aerification, vertical mowing or any other practice which increased light penetration to the soil increased the germination of annual bluegrass seeds. Maximum germination of annual bluegrass seed occurs at end of summer when the temperature is between 21 and 27°C with significant reductions in germination occurring when the temperature exceeds 27c (4). Annual bluegrass initiates growth when the air temperature reaches 13°C with maximum growth occurring when day temperatures are near 21°C and night temperatures are near 16°C (4,24).

It has been reported that annual bluegrass possesses a short root system and will not persist throughout the growing season (44). Support is given to this belief because annual bluegrass often dies during periods of heat and moisture stress. However, the short roots of annual bluegrass most often result from the soil conditions in which it grows and is not an inherent characteristic of the plant (24). The effects of soil conditions on annual bluegrass roots were confirmed by experiments conducted by Sprague and Burton (39). Annual bluegrass, Kentucky bluegrass and colonial bentgrass were grown in similarly compacted soils. When roots were weighed annual bluegrass had 87% of its roots in the upper 7.6 cm whereas Kentucky bluegrass and colonial bentgrass had 92 and 88% of their roots in the same region respectively. In the region below 13 cm annual bluegrass had 6% of its roots and Kentucky bluegrass and colonial bentgrass had 7 and 4% of their roots in that region respectively.

Bentgrasses (*Agrostis* spp.) include over 100 species some of which form a fine-textured, dense turf. Bentgrasses can be utilized in several areas on golf courses, tolerating repeated close mowing. Creeping bentgrass is a native of Northern Europe and is a long lived-perennial. Creeping bentgrass is found in the cool humid region and the cooler areas of the transition zone (3,16). In some warm season areas, bentgrass greens are becoming more frequent. Bentgrasses are aggressive species with growth habits ranging from a slightly stoloniferous, bunch-type species to a species with very aggressive stolon production (3). The aggressiveness of bentgrass was demonstrated by experiments conducted by Davis (14). Astoria bentgrass and other grass species were seeded alone and maintained at 1.9 and 5 cm heights of cut, after five years the Astoria plots contained 100% bentgrass while the other species were subject to weed invasion (14). In another experiment a mixture of bentgrass, redtop (*Agrostis alba* L.) and bluegrass were seeded together, after three years bentgrass dominated the stand (14). Three bentgrass species are commonly used in turf: creeping bentgrass (*Agrostis palustris* Huds.), colonial bentgrass (*A. tenuis* Sibth.), and velvet bentgrass (*A. canina* L.).

Creeping bentgrass is one of the most aggressive turfgrass species used on golf courses and spreads by stolons which root at the nodes. Creeping bentgrass forms a fibrous root system which is annual in nature (3). The root system of creeping bentgrass is moderate in depth being similar to Kentucky bluegrass (*Poa pratensis* L.) and annual bluegrass (3,24,39).

One of the characteristics of creeping bentgrass which makes it suitable for golf course use is the wide range of mowing heights which it can tolerate. Creeping bentgrass is adapted to heights of cut between 0.5 and 1.3 cm. When mowed at these heights creeping bentgrass forms a very dense turf which makes it especially suitable for use on golf course greens and fairways (40). While creeping bentgrass is a vigorous turfgrass it also has a tendency to form thatch when cut at heights greater than 1.3 cm (43).

Although creeping bentgrass forms a fine-textured, dense turf it requires a high level of management. Creeping bentgrass is susceptible to most of the same diseases as annual bluegrass (41).

Brede and Duich (10) studied the interaction between three turfgrass species. They fount that dominance of a turfgrass can occur due to interaction above ground, below ground, or both (10). High plant populations result in competition between plants for light, water, and nutrients (33,39). The competitive potential of a species can be estimated by the relative tiller rate (RTR) and the greater the RTR the more competitive the species. Annual bluegrass was found to have the highest RTR followed by perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass.(10).

King (29) determined in a study of two pasture grasses, perennial ryegrass (*Lolium perenne* L.) and red fescue (*Festuca rubra* L.), that the growth and establishment of one species was influenced by the presence of the other species. It was also determined that increasing the nutrient level when overseeding favors the dominant, existing species rather than the overseeded seedlings (10). Differences between species are often most pronounced when the plants are seedlings and can influence the competitive ability of the species in a mixed stand (8). King (29) suggests that competition for nutrients supports a *status quo* rather than a change in pasture composition.

Cultural practices play an important role in the composition and competitiveness of species in mixed stands. Changing management practices such as mowing , irrigation, cultivation, and overseeding can result in shifts in species composition (22).

Mowing is the most basic of all cultural practices and is the periodic removal of turfgrass shoot growth. Mowing is detrimental to turfgrasses (32). Mowing reduces carbohydrate production and storage, the amount of root growth which influences water absorption, results in increased water loss from cut leaves, and creates points for disease entry (3,40). Mowing upsets the normal process of growth and results in a reduction in photosynthate which is associated with the loss of leaf surface . Repeated clipping was found to increase summer decline of turf (33). Madison (33) found that the weight of `Seaside´ bentgrass roots in the top 15 cm of the soil was not affected by mowing, fertility, or irrigation. However, between 15-30 cm frequent mowing reduced root weight. Mowing less frequently often results in the stronger plants becoming larger and shading the smaller, weaker plants than the overseeded seedlings (10). Differences between species are often most pronounced when the plants are seedlings and can influence the competitive ability of the species in a mixed stand (8). King (29) suggests that competition for nutrients supports a *status quo* rather than a change in pasture composition.

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(34). Repeated mowing and turning with tractor drawn fairway mowers results in severe wear near greens. The repeated turns also result in greater soil compaction which reduces drainage (40). When the density of a turfgrass stand is reduced, annual bluegrass and other weeds can invade (9,19).

By changing from conventional fairway gang mowers to triplex or lightweight fairway mowers much of the soil compaction and wear near the greens is alleviated (17,37). The change in equipment also allows the height of cut to be reduced from 1.9 to 2.5 cm for the fairway gang mowers to 1.3 cm or less for the lightweight or triplex mowers (37).

Reducing the mowing height has several effects on a turf stand including a reduction in carbohydrate synthesis and storage, an increase in shoot density, and a decrease in root growth and total root production (3,40). Moderate, frequent defoliation causes an increase in rhizome and stolon production while, excess defoliation restricts rhizome and stolon production (3,40). Height of cut was shown to significantly influence tillering and shoot dry weight of annual bluegrass when grown with Kentucky bluegrass (6). When the turf was grown above 2.5 cm annual bluegrass had decreased shoot density, shoot dry weight, and tiller number (6).

Each grass species has an optimum height of cut, reducing the height of cut below the optimum will result in reduced vigor for that species allowing the invasion of a species able to tolerate that cutting height. The optimum cutting height for annual bluegrass was determined to be 2.5 cm (6). Annual bluegrass can, however, tolerate mowing at a 0.32 cm height of cut with additional water and fertilizer (6,37). Creeping bentgrass is a species which tolerates mowing at a height of cut between 0.5 and 1.3 cm (37).

Mowing with lightweight mowers, in addition to reducing compaction and turfgrass wear, allows for collection of clippings. According to Beard (3) clippings should be removed when the clippings are excessively heavy, become a hindrance to the purpose of the turf, or lead to disease or other turfgrass damage. Clipping removal can also increase the aesthetic quality of the turf.

Clipping removal has been shown to significantly reduce annual bluegrass populations when grown in mixed stands with creeping bentgrass (37). Clipping removal can also help control annual bluegrass by reducing the number of seeds which fall to the ground (4). Gaussion (22) reported that clipping removal significantly reduced the number of viable annual bluegrass seeds found in the soil. After three years a 60% reduction in the number of viable seeds were observed where clippings were removed.

Clipping removal also affects the amount nutrients in the plant. In a study conducted by Sheard (38), on bentgrass "microgreens" in which clippings and drainage water could be collected, 60 and 34% of the applied nitrogen and potassium, respectively were removed in the clippings. Daniel and Freeborg (13) found under field conditions, over a three year period, that 33% more N had to be applied to plots where clippings were removed to achieve the same color and density as the plots where clippings were returned. Soil samples taken from plots where clippings were removed had significantly less K than from soil samples taken where clippings were returned (22). Phosphorus levels in soil and tissue samples were found to be unaffected by clipping removal (22).

Fertility also plays a major role in determining the species composition of turfgrass areas. Ong *et al.* (36) found that a high nutrient concentration had several effects on annual bluegrass flowering and seed production. Increased nutrient concentration increased length and number of inflorescence branches and spiklets, and increased seed production. Ong *et al.* also reported that high nutrient supply during vegetative growth accelerated inflorescence appearance and increased the number of tillers per plant. Changing the nutrient concentration during vegetative growth also influenced seed production. When nutrient concentration was reduced from high to low 23 days following annual bluegrass emergence the plants produced 50% fewer seeds when compared to annual bluegrass plants that were given high nutrient concentrations continuously (36).

By manipulating the amount and timing of N application the dominance from one species to another can be changed (40). A study conducted on a mixed annual bluegrass and creeping bentgrass turf overseeded with `Seaside´ bentgrass found that where no N was applied there was a 67% increase in bentgrass population after three years, while when fertilized with 48 kg N ha^{-1} had a 44% increase in bentgrass population (15).

The temperature at the time N is available impacts the growth rate. Engel (20) reported that when nitrogen was applied to mixed annual bluegrass and creeping bentgrass stands, cool weather application increased annual bluegrass compared to when N was applied in frequent small applications or in warm weather. Application of N in the fall also affects the turfgrasses ability to harden and increases the likelihood of winterkill.

The form of N fertilizer applied also has an effect on species composition (18). Eggens and Wright found in the greenhouse that when the concentration of NH_4^+ in solution was 25% or more the competitiveness of annual bluegrass was decreased. The reduced competitive ability was made evident by a reduction in shoot and root dry weight, and tiller production. However, Penncross creeping bentgrass was less affected by the form of N than annual bluegrass.

Annual bluegrass encroachment into `Merion´ Kentucky bluegrass was increased by heavy spring N application and applications of activated sewage sludge (4). Density of bentgrass was decreased by application of organic sources of N permitting greater annual bluegrass invasion (39). However, increased N rates were reported to decrease annual bluegrass invasion into mixed stands of Merion Kentucky bluegrass and Common bermudagrass (*Cynodon dactylon* L.)(31).

Christians *et al.* (12) found that creeping bentgrass required less N to maximize quality while increased N was required for maximum growth. Madison (32) found that frequent irrigation and increased N increased the population density of `Seaside' creeping bentgrass. Madison found with respect to N fertilization that an inverse relationship exists between population density and root growth in the top 15 cm of the soil. Root weight decreased in the top 15 cm while population density increased with increases in N fertility. When acid forming fertilizers were used under wet conditions annual bluegrass invasion was reduced (39).

Nitrogen fertilization in general was found to stimulate vegetative growth and at high rates reduce seedhead production. Application of nitrate of soda reduced annual bluegrass seedhead production 50% (39). Juska and Hanson (28) also found that annual bluegrass seedhead production is reduced as soil pH is lowered. This was substantiated by Goss *et al.* (26), when they found that seedhead production increased as the pH of the soil increased from 4.5 to 6.5.

Waddington *et al.* (42) found that the amount of annual bluegrass invasion increased with additions of phosphorus and potassium, especially P. Annual bluegrass invasion on putting greens was found to increase when P was applied at 86 kg ha^{-1} (26). Sprague and Burton (39) reported that application of P and K stimulated production of annual bluegrass seed. Gibeault (24) found that annual bluegrass is more susceptible to shortages of phosphorus than other turfgrasses. Studies conducted by Dest and Guillard (15) contradict the findings of other researchers in that P did not significantly influence annual bluegrass and creeping bentgrass competition.

Phosphorus available in amounts as small as 1 to 2 ppm in the nutrient solution was adequate for bentgrass growth (5). This was confirmed by Christians *et al.* (12) when P in concentrations greater than 2 ppm had no significant effect on bentgrass growth or quality.

Potassium is the second most needed element for turfgrass growth but, the amount of K needed is not really known (3,35). Hylton *et al.* (27) determined that the amount of K needed is influenced by the amount of Na present. Potassium is available to the turfgrass plant from the soil solution or from exchange sites. Gaussion (22) found that there was significantly less K in the soil where clippings were removed compared to where clippings were returned. Bentgrass growth increased in a linear fashion in response to

K when grown in pots under controlled environmental conditions (12). Bell and DeFrance (5) found that for three species of bentgrass, K had a favorable influence on the quality of the turf, but did not significantly influence daily production. Potassium was found to be beneficial to the development of frost hardiness and increased winter survival (1). Potassium also affects leaf and tiller size, tiller number, and dry weight (27).

Research indicates that an interaction exists between N and K fertility (1,35). Applications of high N depleted soil K (35). Monroe (35) found that at low N rates, all levels of K increased growth. Increasing the K:N ratio increases top and root growth and the quality of the turf maximized (12,35).

While much has been reported about how N, K, and clipping removal influences the growth of individual turfgrasses little information exists on how these factors interact and influence species composition of fairway turf. The purpose of this investigation was to determine how nitrogen, potassium, and clipping removal influence annual bluegrass and creeping bentgrass interference under fairway conditions.

Material and Methods

Research was initiated the first week of April in 1986, on a mature stand of annual bluegrass (*Poa annua* var. *reptans* Hausskn. (Timm.)) at the Robert Hancock Turfgrass Research Center Michigan State University. Plots measuring 1.8 X 1.2 m were spot treated with fluazifop-butyl (($\pm$)-butyl 2-[4-[(5-(trifluoromethyl)-2-pyridinyl)oxy]phenoxy]propanoate) at a rate of 0.39 and 0.28 kg ha^{-1} in April 1986 and June 1987 respectively, with a CO_2 backpack sprayer equipped with a single 8002E nozzle calibrated to deliver 262 L ha^{-1} at 0.21 MPa, to eliminate wild type creeping bentgrass from the study area. Following fluazifop-butyl treatment three plugs of Penncross creeping bentgrass (*Agrostis palustris* Huds. cv. \`Penncross´) measuring 91 cm^2 were transferred into each plot. The bentgrass plugs were allowed to become established prior to clipping and fertilizer treatment.

Clipping treatment consisted of mowing the entire study area with a triplex mower at 13 mm height of cut (bench setting) with the catch baskets removed (clipping returned) then replacing the baskets and re-mowing half the study area collecting the clippings (clippings removed). The clipping treatments were started in May of each year and continued through October.

Table 1. Schedule of nitrogen application for the annual bluegrass and creeping bentgrass interference study.

RATE	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
(kg N ha^{-1} yr^{-1})	--------------(kg N ha^{-1})--------------						
293	48	48	48	48	48	0	48
98	24	24	0	0	24	0	24
48	12	12	0	0	12	0	12
0	0	0	0	0	0	0	0

Table 2. Schedule of potassium application for the annual bluegrass and creeping bentgrass interference study.

RATE	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
(kg K ha^{-1} yr^{-1})	--------------(kg K ha^{-1})--------------						
293	48	48	48	48	48	24	0
98	24	24	0	0	24	24	0
0	0	0	0	0	0	0	0

Nitrogen fertilizer was applied at rates of 293, 98, 49, and 0 kg ha^{-1} yr^{-1} and potassium (K_2O) at rates of 293, 98, and 0 kg ha^{-1} yr^{-1} according to the schedules in Tables 1 and 2. Urea (46-0-0) served as the nitrogen carrier and muriate of potash (0-0-60) was the potassium carrier. Both the nitrogen and the potassium were applied with a drop-type spreader.

The experimental design for this experiment was a split plot with three replications. The treatment design was a 2 X 4 X 3 factorial with clipping treatment as the main plot and nitrogen and potassium treatments as sub-plots.

Data collection consisted of taking initial bentgrass spread measurements in May 1986, then taking spread measurements again in October of 1986 and 1987. Bentgrass spread was determined by placing a clear acetate film over the bentgrass core and tracing the perimeter of the core with a permanent marker. The area of the trace was determined using a digital planimeter. An analysis of variance was conducted on the amount of bentgrass spread determined in October 1986 (year one), October 1987 (year two), and the total change in creeping bentgrass spread over both years.

Results and Discussion

The analysis of variance of creeping bentgrass spread indicates that in 1986 (year 1) none of the factors investigated had a significant effect on creeping bentgrass spread (Table 3). However, in 1987 (year 2) and for the total spread of creeping bentgrass, nitrogen rate was found to have a highly significant effect.

Decreasing the rate of nitrogen increased the spread of creeping bentgrass (Table 4). The increase in creeping bentgrass spread corresponded to a decrease in the annual bluegrass population. Table 4 illustrates that plots which received no N had the greatest creeping bentgrass spread and the plots fertilized with 293 kg N ha^{-1} yr^{-1} had the least increase in creeping bentgrass spread. These results are consistent with the results determined by Madison (32) who found that when annual bluegrass was overseeded with \`Seaside´ creeping bentgrass (*A. palustris* Huds. cv. \`Seaside´), as the rate of nitrogen was reduced the population density of the creeping bentgrass increased. Gaussion (22) also found that when mixed annual bluegrass and creeping bentgrass were fertilized at 293 kg N ha^{-1} yr^{-1} annual bluegrass populations increased compared to when fertilized with 98 kg N ha^{-1} yr^{-1}, the increase in annual

Table 3. Analysis of variance of creeping bentgrass spread as influenced by nitrogen, potassium, and clipping treatment in a mixed annual bluegrass and creeping bentgrass turf for 1986, 1987, and combined over both years.

Main Effects	df	1986	1987	1986-1987
Clipping Trmt (C)	1	NS	NS	NS
Nitrogen (N)	3	NS	**	**
Potassium (K)	2	NS	NS	NS
Interactions				
C X N	3	NS	NS	NS
C X K	2	NS	NS	NS
N X K	6	NS	NS	NS
C X N X K	6	NS	NS	NS

** and NS indicates significance at p=0.01 and not significant respectively

Table 4. Main effect means of planimeter measurements of creeping bentgrass spread in response to nitrogen treatment on annual bluegrass and creeping bentgrass interference for 1986, 1987, and total increase in creeping bentgrass spread.

Nitrogen rate	YEAR		
($kg\ ha^{-1}\ yr^{-1}$)	1986	1987	Total
	cm^{-2}		
0	30	1368	1398
48	26	1163	1188
98	17	1201	1218
293	24	828	851
LSD (0.05)	NS	175	179

bluegrass, however,occurred in only one year of a three year study.

Clipping removal has been found to reduce the number of seeds present in the soil, to lower the overall nutrient status of the soil, especially K, and decrease the population of annual bluegrass (22). Under the conditions of this experiment neither the potassium level nor the clipping treatment were determined to significantly influence creeping bentgrass spread.

The response of the clipping treatment in this experiment may be the result of how the treatment was applied. The entire study area was first mowed with the clippings being returned, then the clipping removed half of the study was mowed a second time in which the clippings were removed. This method of clipping removal may have affected the study in several ways. First, because annual bluegrass produces such a large number of seeds which can mature on or off the panicle, many of the seeds which would have been removed may have fallen to the soil, resulting in increased annual bluegrass germination (4,22). Second, the effects of double mowing may have decreased creeping bentgrass stolon production limiting bentgrass spread. Double mowing may have resulted in a reduction of creeping bentgrass vigor minimizing the beneficial effects of clipping removal. Third, return of the clippings and seeds may have also led to the suppression of creeping bentgrass growth by allelo-chemicals in the clippings and seeds of annual bluegrass as described by Fales and Wakefield (21) and by Brede and Harris (11). Finally, although the clippings were collected when mowed the second time some of the clippings may have remained, hence returning some of the nutrients, which might favor annual bluegrass growth (42)

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CHAPTER TWO

Effects of chemical treatment, cultivation practice, and seeding rate on creeping bentgrass overseeded into annual bluegrass.

Introduction

Close mowing, compaction, and excess nitrogen and water have resulted in annual bluegrass (*Poa annua* L.)becoming a major component of many golf course fairways (31). Because annual bluegrass has limited tolerance to temperature and drought stresses, and produces profuse seedheads it is considered an undesirable species and attempts are made to eliminate it (1,10,28). Creeping bentgrass (*Agrostis palustris* Huds.)is an aggressive, perennial turfgrass which forms a dense turf when mowed between 5 and 13 mm and is especially suited for golf course fairways (30).

In the past, attempts to convert predominantly annual bluegrass fairways to other turfgrasses, which may provide a more consistent playing surface, have been mostly unsuccessful (11). In highly managed turfgrass stands with high populations of annual bluegrass it is costly to introduce bentgrass species (8). Establishment of creeping bentgrass by overseeding into existing annual bluegrass is also reduced because seedlings are poor competitors in a dense stand of established grasses (32).

King (22) found that the introduction of more desirable species into an existing species could be increased by use of cultivation treatments. On a green containing more than 50% annual bluegrass, deep core cultivation and overseeding with 'Seaside' creeping bentgrass significantly reduced the amount of annual bluegrass (24). Vertical mowing significantly increased overseeded perennial ryegrass emergence on a bermudagrass green (20).

King (22) also found that chemical treatment could increase the introduction of new more desirable species into existing species. However, the use of herbicides with a long soil residual may prevent the germination of overseeded desirable species (19,21).

Engel and Aldrich (13) report that annual bluegrass could be controlled in mixed stands by several ways: 1) eliminating annual reseeding by use of herbicides and growth regulators, 2) applications of preemergence herbicides, 3) plant eradication using postemergence and non-selective herbicides, or 4) a combination of treatments. Jagschitz (18) in tests of several preemergence herbicides for controlling annual bluegrass found that bensulide (*O,O* - diisopropyl phosphorodithioate *S*-ester with *N*-(2-mercaptoethyl) benzenesulfonamide) gave annual bluegrass control ranging between 81 to 96% for the second through fourth years of an experiment. Benefin (*N*-butyl-*N*-ethyl-α,α,α,-trifluoro-2,6-dinitro-*p*-toluidine), DCPA (dimethyl tetrachloroterephthalate), oxidiazon (2-*tert*-butyl-4-(2,4 dichloro-5-isopropoxyphenyl)-2-1,3,4-oxidiazolin-5-one), and siduron (1-(2-methylcyclohexyl)-3-phenylurea) gave less than 68% control over the save time period (18). Lead arsenate when applied at 240 kg ha^{-1} controlled annual bluegrass however, high rates and repeated applications of lead arsenate can be toxic to bentgrasses (21,28). Endothall (7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid) applied at 0.56 kg ha^{-1} and sodium arsenate + 2,4-D ((2,4-dichlorophenoxy)acetic acid) applied at 1.12 + 0.22 kg ha^{-1} increased creeping bentgrass 17 and 10% respectively compared to no change in the control. McMaugh (23) found that endothall applied at rates above 0.28 kg ha^{-1} damaged colonial bentgrass and creeping bentgrass. Endothall applied below 0.14 kg ha^{-1} did not control annual bluegrass. Seeds of colonial bentgrass sprayed with endothall at a rate of 0.28 kg ha^{-1} germinated 10 days following planting. Treatment with endothall one week following emergence did not damage the colonial bentgrass seedlings (23). Cisar *et al.* (4) found that Penncross creeping bentgrass was more tolerant of herbicide treatment and allowed less invasion of of annual bluegrass than Kingston velvet bentgrass (*A canina* L) or Emerald creeping bentgrass.

In field studies using fenarimol (2-(2-chlorophenyl)-2-(4-chlorophenyl)-5-pyrimidinemethanol), annual bluegrass was not reduced in mixed populations of annual bluegrass and creeping bentgrass (14). Gaul and Christians (14) also found that chlorsulfuron ({2-chloro-N[(4-methoxy-6-methyl-1,3,5-triazin-2yl)-aminocarbonyl]-benzenesulfonamide}) gave no preemergence annual bluegrass control. They also found that the perennial type of annual bluegrass demonstrated a higher degree of tolerance to many chemical treatments compared to the annual biotype.

Ethofumesate (2-ethoxy-2,3dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate) has been reported to have preemergencee and postemergence effects on annual bluegrass(2,9,26). Ethofumesate controlled annual bluegrass in renovated stands of perennial ryegrass (2).

Single applications of ethofumesate were found to control annual bluegrass, however, acceptable control to a turf manager (>75% control) was achieved only after multiple applications of 1.1 kg ha^{-1}. In non-overseeded bermudagrass, ethofumesate applied in multiple applications gave greater than 70% annual bluegrass controll (5).

Ethofumesate and pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) controlled annual weeds in bentgrass turf, however, ethofumesate treatment was phytotoxic and resulted in reduced quality (4). Dickens (9) indicated that ethofumesate treatment at overseeding, prior to bermudagrass dormancy resulted in stoppage of bermudagrass growth.

The use of plant growth regulators as a tool for changing the composition of turfgrass areas has been studied. Maleic hydrazide (1,2-dihydro-3, 6 pyridinedione) applied at 0.56 and 1.12 kg ha^{-1} reduced the spread of zoysiagrass (*Zoysia japonica* Steud.) 10 and 30% respectively. These findings were similar to Engel and Aldrich (13) who found that creeping bentgrass was reduced 29% when maleic hydraizide was applied at 1.12 kg ha^{-1}.

Hubbell and Dunn (17) determined that mefluidide [N-(2,4-dimethyl-5{[(trifluoromethyl)sulfonyl]amino}phenyl)acetamide] applied at 0.28 kg ha^{-1} increased the spread of zoysiagrass 20% into Kentucky bluegrass. Seedhead production was reduced by mefluidide with rates between 0.07 and 0.28 kg ha^{-1} (25). Rate and timing of mefluidide was shown to have a significant effect on annual bluegrass seedhead production (3,7).

Mefluidide has been shown to result in a thinning of turf and a reduction in turf quality (6,17). The reduction in density and quality lasts for approximatly four weeks.

Mefluidide application to fairways proir to overseeding has been shown to reduce the competitive ability of annual bluegrass (12). Mefluidide applied at rates between 0.1 and 0.4 kg ha^{-1} to annual bluegrass plots, then overseeded with a mix of perennial ryegrass and creeping bentgrass had significantly more perennial ryegrass at the 0.4 kg ha^{-1} mefluidide treatment two months following overseeding (12).

Shoop *et al.* (27) found that flurprimidol α(1-methylethyl-α-[4-(trifluoromethoxy)phenyl]-5-pyrimidine methanol) reduced annual bluegrass in mixed annual bluegrass and creeping bentgrass stands. Flurprimidol was found to have some preemergence activity on annual bluegrass and creeping bentgrass seeds in the soil with rates in excess of 0.56 kg ha^{-1} reducing germination (15). Gaussoin (15) suggests that use of flurprimidol at or near the time of overseeding should be avoided.

In an attempt to convert a predominately annual bluegrass fairway to creeping bentgrass without complete renovation, several aspects of fairway overseeding were investigated: 1) the effects of herbicides and plant growth regulators on overseeding creeping bentgrass, 2) to determine whether cultivation increases the establishment of overseeded creeping bentgrass, and 3) to determine the optimal seeding rate for efficient at establishment of creeping bentgrass into an existing annual bluegrass stand.

Materials and Methods

A two year study was conducted at the Robert Hancock Turfgrass Research Center. All overseeding studies were conducted on an Owosso-Marlette sandy loam complex (fine-loamy, mixed, mesic, Typic, Glossoboric Hapludalfs) maintained at 13 mm height of cut (bench setting) with a triplex mower with the clippings returned. All treatments received adequate water and fungicides as needed.

Prior to overseeding the study area was treated with fluazifop-butyl ((±)-butyl 2-[4-[(5-(trifluoromethyl)-2-pyridinyl)oxy]phenoxy]propanoate) to suppress all wild type creeping bentgrass from the study areas. Fluazifop-butyl was applied on 1 July 1986 and 18 June 1987 at rates of 0.39 and 0.28 kg ha^{-1}, respectively, with a backpack CO_2 sprayer equipped with a 8002E nozzle. The sprayer was calibrated to deliver 262 L ha^{-1} at 0.21 MPa.

Cultivation treatments consisted of either core cultivation, vertical mowing, or no cultivation. Core cultivation treatment consisted of one pass with a greens aerifier with 0.95 cm diameter x 7.5 cm hollow tines. The cores were allowed to dry then broken up using a vertical mower with the blades set deep enough to break up the cores but not the soil surface. Vertical mowing treatments were applied with a walk behind vertical mower with blades set to penetrate the soil surface 0.32 cm (bench setting). Starter fertilizer was applied at a rate of 48 kg N ha^{-1}. Prior to broadcast overseeding, the cultivation treatment and starter fertilizer were applied. Following overseeding the study area was dragged with a mat to incorporate the seed, rolled to insure good seed to soil contact, and irrigated to keep moist. All herbicides and plant growth regulators tested were applied with a four nozzle hand held CO_2 backpack sprayer equiped with 8002 nozzles. The sprayer was calibrated to deliver 472 L ha^{-1} at 0.21 MPa. Granular materials were applied using a drop spreader.

For all overseeding studies, data was collected on the percent creeping bentgrass present. Creeping bentgrass plant populations were estimated using the vertical point quadrat method described by Tinney *et al.* (29). A grid was made with 112 intersections on 100 mm centers with monofilament line on a PVC frame measuring 1.8 X 1.2 m. The frame and grid was placed on top of each plot and the plant beneath each intersection determined, and if it was a creeping bentgrass plant it was counted. The number of counts per plot was divided by 112 and multiplied by 100 which gave an estimate of percent creeping bentgrass in each plot. An analysis of variance was conducted on the percent creeping bentgrass present and where significant differences occurred means were compared using an LSD.

1986 Overseeding Study

In 1986 an overseeding study was conducted in which the experimental design was a randomized complete block design and the treatment design was a 3 x 3 x 5 factorial arrangement with three replications. The first factor was seeding rate which was either 48, 98, 195 kg ha^{-1} of `Penncross´ creeping bentgrass seed. The second factor of the 1986 overseeding study was cultivation treatment which consisted of either core cultivation, vertical mowing, or no cultivation. The last factor of the 1986 overseeding study was chemical treatment with the following products tested: mefluidide, mefluidide + ethofumesate, glyphosate (*N*-(phosphonomethyl)glycine), glyphosate + ethofumesate, and no chemical treatment (control). The rates and timing of application are described in Table 5. On 14 August 1986 cultivation treatments and starter fertilizer were applied, and then the plots were overseeded. Following overseeding the area was dragged, rolled, and irrigated as previously described.

Four weeks following overseeding the ethofumesate treatments were applied. Ethofumesate application consisted of applying 1.12 kg ai ha^{-1} on 16 September and again on 15 October 1986.

Creeping bentgrass estimates were determined by plant counts made 2 November 1986 and by visual estimates of percent creeping bentgrass population made on 13 July 1987.

Table 5. Chemical treatments and rates and dates of application for the 1986 overseeding study conducted to examine the effects of herbicides and plant growth regulators, seeding rate, and cultivation treatment on creeping bentgrass establishment.

TREATMENT	RATE	DATE APPLIED
	-------(kg ha^{-1})-------	
Glyphosate (Gly)	4.5 ai	8/4
Mefluidide (Mef)	0.28 ai	8/4
Gly + Etho(4W)*	4.5 ai+(1.12+1.12 ai)	8/4+(9/16+10/15)
Mef + Etho(4W)	0.28 ai+(1.12+1.12 ai)	8/4+(9/16+10/15)
No Chemical	------------	------------

* 4W indicates first ethofumesate application and is 4 weeks after overseeding

Table 6. Chemical treatments and rates and dates of application for the 1987 overseeding study conducted to examine the effects of herbicides and plant growth regulators on creeping bentgrass establishment

TREATMENT	RATE (kg ha^{-1})	DATE APPLIED
	-------(kg ha^{-1})-------	
Glyphosate (Gly)	1.12	7/30
Ethofumesate (Etho)(4W)*	(0.43 + 0.84 ai)	(9/15 + 10/15)
Etho (5W)	(0.43 + 0.84 ai)	(9/21 + 10/19)
Etho (6W)	(0.84 + 0.84 ai)	(9/29 + 10/27)
Etho (dormant seeded)	(0.84 + 0.84 ai)	(9/15 + 10/15)
Etho (dormant seeded)	(1.7 + 1.7 ai)	(9/15 + 10/15)
Mefluidide (Mef)	0.28 ai	8/10
Mef	0.43 ai	8/10
Mef	0.56 ai	8/10
Flurprimidol (Flur)	1.12 ai	7/28
Gly + Etho(6W)	1.12+(0.84+0.84 ai)	7/30+(9/29+10/27)
Mef + Etho(3W)	0.43ai+(0.43+0.84 ai)	8/10+(9/9+10/6)
Mef + Etho(3W)	0.43ai+(0.28+1.12 ai)	8/10+(9/9+10/6)
Mef + Etho(6W)	0.43ai+(0.84+0.84 ai)	8/10+(9/29+10/27)
Flur + Etho(6W)	1.12+(0.84+0.84 ai)	7/28+(9/29+10/27)
No Chemical	------------	------------

* 3W, 4W,5W, and 6W indicates first ethofumesate application and is 3, 4, 5, or 6 weeks after emergence

1987 Overseeding Studies

The large factorial study conducted in 1986 was divided into two individual studies in 1987. The division enabled additional treatments to be included, while maintaining the treatments of the 1986 overseeding study. The first study conducted 1987 was an investigation into the effects of various herbicides and plant growth regulators on the establishmnet of overseeded creeping bentgrass. The second study reexamined the effects of seeding rate and cultivation on establishment of overseeded creeping bentgrass.

The chemicals applied, the rate, and date of application for the study examining the effects of herbicides and plant growth regulators on overseeding are given in Table 6. Application of flurprimidol occurred 14 days prior to overseeding (28 July 1987), glyphosate treatment was applied 12 days prior to overseeding (30 July 1987), and mefluidide two days prior to overseeding (10 August 1987). The ethofumesate treatments were applied in two applications at the rates listed (Table 6) with the first application being applied either 3, 4, 5, or 6 weeks following creeping bentgrass emergence (3, 4, 5, and 6 W) the second application was then applied 30 days following the first.

On 12 August 1987, the study area was vertical mowed in two perpendicular directions and the debris was removed, starter fertilizer was applied, and the area was overseeded by hand with 98 kg ha^{-1} 'Penncross' creeping bentgrass seed. Following overseeding the area was dragged, rolled, and irrigated.

The experimental design of this study was a randomized complete block design with three replications. To determine percent creeping bentgrass establishment plant counts were taken two weeks following the last ethofumesate treatment, on 14 November 1987 and again on 23 June 1988.

A second overseeding study was initiated in 1987 to examine the effects of seeding rate and cultivation on the establishment of overseeded creeping bentgrass. The experimental design was a randomized complete block design with three replications. The treatment design was a 3 x 3 factorial. The factors in this were seeding rate and cultivation. The seeding rates in this study were 48, 98, and 195 kg ha^{-1} of 'Penncross' creeping bentgrass seed. The cultivation treatments were core cultivation, vertical mowing, and no cutivation. The seeding rates and cultivation treatments used in this study were the same treatments used in the 1986 overseeding study and were applied in the same manner. The cultivation treatments, starter fertilizer, and overseeding treatments were applied on 11 August 1987. Plant counts to determine percent creeping bentgrass establishment using the previously described method were taken 14 November 1987 and 23 June 1988.

Results and Discussion

1986 Overseeding Study

The analysis of variance of the fall counts taken for the 1986 overseeding study indicate that the main effects of seeding rate and chemical treatment had a highly significant effect ($p=0.01$) on creeping bentgrass establishment. Neither cultivation nor any of the interactions resulted in significant differences in creeping bentgrass establishment (Table 7).

Fall plant counts indicated that overseeding with 98 and 195 kg ha^{-1} Penncross creeping bentgrass seed resulted in significantly more creeping bentgrass establishment than 49 kg ha^{-1}, with no significant difference between the 98 and 195 kg ha^{-1} seeding rates (Table 8).

Treatment with glyphosate resulted in the greatest establishment of creeping bentgrass in the fall following overseeding (Table 9). Treatment with glyphosate + ethofumesate resulted in significantly less creeping bentgrass than the glyphosate alone treatment but more creeping bentgrass establishment than the control or any of the other treatments. Treatment with ethofumesate four weeks following overseeding resulted in bentgrass injury which decreased bentgrass establishment. Ethofumesate has been shown by others to result in injury to desirable

Table 7. Analysis of variance of percent creeping bentgrass establishment for 1986 overseeding study.

Main Effects	df	FALL 1986	SUMMER 1987
Seeding Rate (S)	2	**	NS
Cultivation (C)	2	NS	NS
Chemical Treat. (T)	4	**	**
Interactions			
S X C	4	NS	NS
S X T	8	NS	NS
C X T	8	NS	NS
S X C X T	16	NS	NS

** and NS indicates significance at p=0.01 and not significant respectively

Table 8. Main effect means of seeding rate on percent establishment of overseeded creeping bentgrasss into annual bluegrass for the 1986 overseeding study. Means averaged over cultivation.

SEEDING RATE (kg ha^{-1})	FALL 1986 -- % COVER --
48	6.2
98	9.6
195	10.1
LSD (0.05)	2.9

species (9,19,26). In a greenhouse experiment (5) preemergence application of ethofumesate resulted in creeping bentgrass seedling mortality.

Plant counts taken in the fall of 1986 indicate that the overall establishment of creeping bentgrass was very low. The decreased bentgrass establishment may have resulted from the excessive rains which fell in September and October that may have decreased the germination and establishment of the overseeded creeping bentgrass.

Analysis of visual estimates of percent creeping bentgrass cover made in the summer of 1987 indicate that only chemical treatment had a significant effect on the establishment of overseeded creeping bentgrass (Table 7). Glyphosate + ethofumesate (4.5 kg ha^{-1} + (1.12 + 1.12 kg ai ha^{-1}) resulted in significantly more creeping bentgrass (82%) than any of the other treatments (Table 9). The data also indicate that the glyphosate and mefluidide + ethofumesate treatments had significantly more creeping bentgrass than the control or the mefluidide alone treatment.

Ethofumesate has been reported to have preemergence and postemergence activity on annual bluegrass (2,9,26). The activity of ethofumesate on annual bluegrass overseeded with creeping bentgrass was confirmed by comparing the amount of creeping bentgrass present in the fall of 1986 with the amount of creeping bentgrass present in the summer of 1987. Where ethofumesate had been applied, the greatest creeping bentgrass establishment occurred. The preemergence activity of the ethofumesate prevents the germination of the annual bluegrass seeds present in the thatch and soil. The postemergence activity of ethofumesate controlled the existing annual bluegrass, further reducing the pressure exerted by the annual bluegrass.

When compared to control plots, the plots treated with ethofumesate became discolored turning a straw color over winter. The phytotoxicicity of ethofumesate was also noted by Cisar *et al.* (4). In addition to the discoloration ethofumesate also resulted in a reduction in turf density. The discoloration and reduced density continued until the end of May or beginning of June.

1987 Overseeding Studies

Analysis of plant counts taken in the fall 1987 and summer of 1988 examined the effects of herbicides and plant growth regulators on overseeding and indicated that chemical treatment had a highly significant effect on creeping bentgrass establishment. The results of the analysis are summarized in Table 10. Plant counts taken in the fall of 1987 indicate that glyphosate and glyphosate + ethofumesate had the greatest establishment of creeping bentgrass with 62 and 50% creeping bentgrass establishment respectively. A slight decrease in establishment of creeping bentgrass occurred with the application of the ethofumesate which was

Table 9. Main effect means of chemical treatments for 1986 overseeding study of creeping bentgrass into annual bluegrass. Averaged over seeding rate and cultivation.

TREATMENT	FALL 1986	SUMMER 1987
	---------- PERCENT COVER	----------
Glyphosate	20.3	50.7
Mefluidide	3.2	16.1
GLY + ETHO(4W)*	11.6	81.5
MEF + ETHO(4W)	2.3	42.6
NO CHEMICAL	5.7	19.3
LSD (0.05)	3.1	19.0

* 4W INDICATES FIRST ETHOFUMESATE APPLICATION AND IS 4 WEEKS AFTER OVERSEEDING

Table 10. Mean percent creeping bentgrass cover due to chemical treatment for the 1987 study of effects of herbicides and plant growth regulators on establishment of overseeded creeping bentgrass.

TREATMENT	FALL 1987	SUMMER 1988
	------- PERCENT COVER	-------
Glyphosate	62.3	57.0
Ethofumesate (Etho) (4W)*	7.0	25.7
Etho (5W)	3.3	17.3
Etho (6W)	3.0	29.0
Etho (dormant seeded)	0.0	12.7
Etho (dormant seeded)	0.0	58.7
Mefluidide (Mef) (0.28)	12.7	24.7
Mef (0.43)	25.7	33.0
Mef (0.56)	18.3	30.7
Flurprimidol (Flur)	8.3	15.0
Gly + Etho (6W)	50.0	92.0
Mef + Etho (3W) {0.43+(0.28+1.12)}	23.0	73.0
Mef + Etho (3W) {0.43+(0.43+0.84)}	22.3	63.3
Mef + Etho (6W) {0.43+(0.84+0.84)}	33.7	71.0
Flur + Etho (6W)	2.3	41.3
No Chemical	5.3	15.7
LSD (0.05)	14.2	18.2

* 3W, 4W, 5W, and 6W indicates first ethofumesate application and is 3, 4, 5, or 6 weeks after emergence

similar to the decrease which occurred in the 1986 overseeding study where ethofumesate was applied. Plant counts taken in the fall of 1987 also indicate that mefluidide applied at 0.43 kg ai ha^{-1} and, all mefluidide + ethofumesate treatments had significantly more creeping bentgrass than the control (Table 10).

Results of plant counts taken in the summer of 1988 examining the effects of herbicides and plant growth regulators on overseeded creeping bentgrass indicated that treatment with glyphosate + ethofumesate and mefluidide + ethofumesate (0.43 kg ai ha^{-1} + (0.28 +1.12 kg ai ha^{-1}) with initial ethofumesate treatment being applied three weeks following creeping bentgrass emergence (3W) had the greatest creeping bentgrass establishment with 92 and 73% bentgrass cover respectively. Treatment with glyphosate, ethofumesate applied at 1.7 + 1.7 kg ai ha^{-1} and dormant seeded, mefluidide + ethofumesate (0.43 kg ai ha^{-1} + (0.43 +0.84 kg ai ha^{-1} at 3W), mefluidide + ethofumesate (0.43 kg ai ha^{-1} + (0.84 +0.84 kg ai ha^{-1}) at 6W), and flurprimidol + ethofumesate (6W) all had significantly more creeping bentgrass cover than the control.

Plant counts were taken and an analysis of variance was performed on the data to determine the effects of seeding rate and cultivation treatment on establishment of creeping bentgrass overseeded into annual bluegrass. The analysis of variance (Table 11) indicates that the main effects of seeding rate and cultivation were both highly significant in the establishmment of overseeded creeping bentgrass.

The results of seeding rate on the establishment of creeping bentgrass indicates that seeding with 195 kg ha^{-1} of `Penncross´ creeping bentgrass seed resulted in significantly greater establishment of creeping bentgrass than 49 or 98 kg ha^{-1} bentgrass seed (Table 12). The effects of seeding rate in 1987 were slightly different than in 1986. In the fall of 1986 both the 98 and the 195 kg ha^{-1} seeding rates were highly significant (p=0.01) while in 1987 only the 195 kg ha^{-1} rate was significant (p=0.05).

The effects of cultivation treatment on overseeding in 1987 are summarized in Table 13. The results indicate that vertical mowing resulted in significantly greater creeping bentgrass establishment than core cultivation and no cultivation. Core cultivation resulted in significantly more creeping bentgrass establishment than no cultivation (Table 13). Johnson (20) also found that when overseeding bermudagrass putting greens with perennnial ryegrass vertical mowing resulted in significantly greater establishment of perennial ryegrass than when no vertical mowing treatment was applied. While in 1987 both seeding rate and cultivation treatment resulted in significantly greater creeping bentgrass establishment, bentgrass establishment was greater

Table 11. Analysis of variance of plant counts of the 1987 overseeding study to examine the effects of seeding rate and cultivationtreatment on the establishment of overseeded creeping bentgrass.

Source	df	FALL 1987	SUMMER 1988
Seeding rate (S)	2	**	*
Cultivation (C)	2	**	**
S X C	4	NS	NS

*.**, and NS Indicates significance at p=0.05, 0.01, and not significant respectively.

Table 12. Main effect means of seeding rate for the 1987 overseeding study examining the effects of seeding rate and cultivatation on the establishment of creeping bentgrass overseeded into annual bluegrass. Means are averaged over cultivation treatment.

SEEDING RATE	FALL 1987	SUMMER 1988
(kg ha^{-1})	-----PERCENT CREEPING	BENTGRASS-----
48	2.6	5.8
98	2.8	7.6
195	6.8	12.6
LSD (0.05)	2.5	4.6

Table 13. Main effect means of cultivation treatment for the 1987 overseeding study examining the effects of seeding rate and cultivatation on creeping bentgrass establishment overseeded into annual bluegrass. Means averaged over cultivation treatment.

	FALL 1987	SUMMER 1988
Cultivation treatment	---- % creeping bentgrass----	
Vertical Mow	6.6	14.2
Core cultivation	2.8	8.7
No cultivation	2.7	3.0
LSD (0.05)	2.5	4.6

where chemical treatments were applied than where no chemicals were applied.

In summary some type of chemical treatment must be made to reduce the density and interference exerted by the annual bluegrass for successful overseeding of creeping bentgrass. Mefluidide and glyphosate can reduce the population density and interference of the annual bluegrass, increasing the establishment of overseeded creeping bentgrass. However, mefluidide must be applied prior to overseeding to avoid injury to the newly overseeded seedlings. Application of

these chemicals at this time also allowed the germination and establishment of annual bluegrass seeds present in the thatch or soil.

The results of this investigation indicate that the application of mefluidide and glyphosate prior to overseeding results in decreased annual bluegrass interference at the time of overseeding. Ethofumesate application six weeks after emergence then further controls the annual bluegrass in the fall and the next spring allowing for excellent establishment of creeping bentgrass. However, ethofumesate treatment did cause initial bentgrass injury resulting in reduced turfgrass density and discoloration.

Furthermore, while vertical mowing was shown to result in increased bentgrass establishment, cultivation alone does not reduce the interference of the annual bluegrass enough to get substantial bentgrass establishment. In two years of study, 195 kg ha^{-1} of creeping bentgrass seed was determined to result in significantly more bentgrass establishment. However, when seeded at 98 kg ha^{-1} in combination with chemical treatment, greater bentgrass establishment was achieved, indicating that without chemical treatment to reduce annual bluegrass pressure, bentgrass establishment is low regardless of the seeding rate or cultivation treatment employed.

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CHAPTER THREE

Effects of nitrogen and cultivation on thatch accumulation and grass species invasion

Introduction

Cultivation is an important cultural practice in the management of mixed annual bluegrass and creeping bentgrass stands. Cultivation practices modify the physical characteristics of the soil and turf (20). Cultivation can be used to discourage or encourage annual bluegrass growth.

Mechanical cultivation practices, such as core cultivation or "aeration", can increase the amount of soil oxygen. Core cultivation also increases water infiltration and helps disrupt any soil layers which can form below the turf (12). According to Gibeault (9) core cultivation should be done in the spring or early summer when annual bluegrass germination is at a minimum. If coring is done in the fall it should be done later in the season when temperatures are below optimum for annual bluegrass germination (2,12,22).

Seeds of annual bluegrass are often found in the thatch and soil. Cultivation opens the turf to allow the seeds to contact the soil and also reduces turf density allowing for more light to penetrate, increasing annual bluegrass germination (23). In an experiment conducted by Youngner, (23) half a bermudagrass (*Cynodon dactylon* L.) turf was vertical mowed to help control thatch, the other half of the bermudagrass turf was left untouched . One month following vertical mowing, the vertical mowed half was covered with annual bluegrass while the untouched half had only scattered annual bluegrass plants present.

Thatch accumulation often becomes a problem in bentgrass when grown in monostands or in mixed stands with annual bluegrass, when mowed at 13 mm or above (22). Thatch can be defined as the intermingling of living and dead crowns, stolons, stems, rhizomes, and roots which develop above the soil surface (2,15). Shildrick (15) distinguished two types of thatch, fibrous and spongy. Fibrous thatch is tough and wiry in texture and has a high proportion of lignified stems, stolons and roots. Fibrous thatch is commonly found on dry areas and makes wetting the underlying soil difficult. Spongy thatch is often found in waterlogged areas and is accompanied by the smell of stagnation and decay. Crown and stem tissue have a higher concentration of lignin which affects the decomposition of thatch by microorganisms (10). Lignin was found to comprise between 27 and 29% of the tissue in Kentucky bluegrass, red fescue, and colonial bentgrass (10). Turfgrass clippings were found to contain very little lignin and do not contribute to thatch accumulation.

Thatch makes turf more susceptible to scalping, reduces tolerance to cold and drought, and limits water infiltration (21). Ledeboer and Skogley found that many turfgrass roots were located in the upper thatch layer (10). Using radioactive phosphorus it was determined that roots of creeping bentgrass removed nutrients from the thatch and soil (4). Thatch has poor nutrient and water holding capacity (20) and it is often difficult to maintain turf when plant roots are located in the thatch. Core cultivation and vertical mowing were found to increase the amount of soil in the thatch making it a more suitable media for turfgrass growth (6).

Thatch is very porous and contains a large number of air spaces (13,12). The speed at which leaching occurs from thatch is a function of the thatch and the underlying soil. When nitrogen leaching was investigated more leaching occurred from urea and from the thatch than from IBDU and the soil (13). A similar response occurred with nitrogen volatilization with more volatilization occurring from the thatch and with urea than from the soil and IBDU.

Nitrogen was found to result in greater plant growth which caused greater thatch accumulation (17, 9). However, in experiments conducted in Nebraska, applications of nitrogen from 0 to 439 kg ha^{-1} yr^{-1} did not increase thatch accumulation in Kentucky bluegrass or creeping bentgrass (1).

Research conducted on bermudagrass fertilized with 586 kg N ha^{-1} yr^{-1} of activated sewage sludge and ammonia nitrate determined that more thatch developed where activated sewage sludge was applied than nitrate (17).

Potter *et al.* (14) found that earthworms were very important in thatch decomposition and that earthworms were less abundant on fertilized turf. Potter also found that thatch was positively correlated to N rate but was negatively correlated to earthworm density and biomass (14).

Turgeon *et al.* (19) determined that thatch development was not significantly increased by applications of benefin (*N*-butyl-*N*-ethyl-α,α,α,-trifluoro-2,6-dinitro-*p*-toluidine), bensulide (*O,O* -diisopropyl phosphorodithioate *S*-ester with *N*-(2- mercaptoethyl) benzenesulfonamide), or DCPA (dimethyl tetrachloroterephthalate). However, preemergence herbicides calcium arsenate and bandane (polychlorodicyclopentadiene) significantly decreased verdure, root and rhizome growth, and increased thatch development. Growth retardants mefluidide [N-(2,4-dimethyl-5{[(trifluoromethyl)sulfonyl]amino}phenyl)acetamide] and flurprimidolα-(1-methylethyl-α-[4-(trifluoromethoxy)phenyl]-5-pyrimidine methanol) did not affect thatch accumulation (5,16).

Vertical mowing and core cultivation can be used to reduce thatch accumulation (7,11,21). On golf greens topdressing and core cultivation with vertical mowing were found to be the two most effective methods of reducing thatch (1). In experiments conducted by Dunn *et al.* (7) vertical mowing reduced thatch 12 to 18% each year in Zoysiagrass (*Zoysia japonica* Steud.) turf. White and Dickens (21) found when comparing biweekly vertical mowing, twice yearly vertical mowing, and frequent core cultivation, that thatch accumulation in bermudagrass was not affected but, the cultivation practices did help reduce scalping.

Sprague and Burton (17) reported that in areas where abundant annual bluegrass seeds are present and damage to the turf occurs, rapid annual bluegrass invasion can result. When considering annual bluegrass invasion into permanent grasses competition for nutrients, space, and moisture are critical (17).

The amount of annual bluegrass invasion is influenced by the density of the existing turf and aggressiveness of the existing stand. Tests were conducted on two bentgrass turfs, one was Virginia bentgrass, a coarse strain which produces a thin stand, and the other was Metropolitan bentgrass which is an aggressive strain producing a dense stand. After five years and with no additional nitrogen fertilization, the Virginia strain had 18% annual bluegrass and Metropolitan had 4% annual bluegrass (17).

Height of cut and seeding rate were shown to impact annual bluegrass invasion into Kentucky bluegrass. Brede and Duich (3) found that Kentucky bluegrass had less annual bluegrass invasion when mowed at 2.5 cm compared to 1.3 cm and that seeding Kentucky bluegrass at 388 pure live seed dm^{-2} resulted in the least annual bluegrass invasion. An annual bluegrass fairway that was overseeded for three successive years with Kentucky bluegrass showed only a slight increase in Kentucky bluegrass (8). It was postulated that the failure of the Kentucky bluegrass seedlings to become established was the result of shading by the annual bluegrass.

The purpose of this experiment was to examine the effects of nitrogen application rate on thatch development in creeping bentgrass and annual bluegrass and how cultivation practices affect invasion of other grasses.

Material and Methods

A study was initiated in the spring of 1986 at the Robert Hancock Turfgrass Research Center to examine the effects of nitrogen and cultivation on thatch accumulation and species invasion. Research was conducted monostands of on annual bluegrass (*Poa annua* var. *reptans* Hausskn. (Timm.)), Penncross creeping bentgrass (*Agrostis palustris* Huds. cv. `Penncross´, and Penneagle creeping bentgrass ( *A. palustris* Huds. cv. `Penneagle´). The Penncross and Penneagle had been established from seed the fall of 1985. The soil type was an Owosso-Marlette sandy loam complex (fine-loamy, mixed, mesic Typic Glossoboric Hapludalfs). The study area was mowed at a height of 13 mm (bench setting) with a triplex mower. Clippings were removed from the creeping bentgrass plots and the clippings were returned to the annual bluegrass plots. Water and fungicides were applied as needed.

Each turfgrass was divided into plots measuring 1.5 x 1.8 m. The experimental design was a randomized complete block design. The treatment design was a 3 x 3 x 5 factorial design with one split with turfgrass species (cultivar) as the main plot and nitrogen and cultivation treatments were subplots.

Nitrogen and cultivation treatments were initiated in May of 1986 and continued through October of 1987. Nitrogen was applied at rates of 293, 195, and 97 kg N ha^{-1} yr^{-1} according to the schedule in Table 14.

Cultivation treatments consisted of core cultivation (coring) in the spring, fall, or spring and fall; vertical mowing in the spring and fall; and no cultivation. Coring treatments consisted of one pass with a greens aerifier equipped with 9.5 mm diameter x 75 mm hollow tines. The cores were allowed to dry then broken up using a vertical mower, with the blades set deep enough to break up the cores but not reach the soil surface, and reincorporated into the turf. Spring coring treatments were applied in mid-May, and fall coring treatments were applied in mid-October of 1986 and 1987. The vertical mowing treatment consisted of vertical mowing each treatment once each week for four consecutive weeks in the spring and again in the fall, with vertical mower units attached to a triplex mower. The vertical mower blades were spaced 13 mm apart and set 3 mm above the soil surface (bench setting). The depth of the vertical mower blades was deep enough to cut the thatch and stolons but not deep enough to penetrate the soil surface. Spring vertical mowing treatments were initiated at the end of May in 1986 and 1987. The fall vertical mowing treatments were initiated on 14 October 1986 and 17 September 1987.

Table 14. Rate of nitrogen application per month for the study on the effects of nitrogen and cultivation on thatch accumulation and grasks species invasion.

RATE (kg N ha^{-1} yr^{-1})	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
	.... (kg N ha^{-1})						
293	48	48	48	48	48	0	48
195	24	24	24	24	48	0	48
98	24	24	0	0	24	0	24

An estimate of the amount of invasion of grass species was determined by a modification of the vertical point quadrat method described by Tinney (18). A monofiliment grid with 90 intersections on 152 mm centers was made on a PVC frame 1.8 x 1.5 m. The plant beneath each intersection was determined and if it was an invading species it was counted. An invading species was defined in this experiment as an annual bluegrass plant invading into Penncross or Penneagle creeping bentgrass (undesirable invasion) or a creeping bentgrass plant invading into the annual bluegrass (desirable invasion). At the beginning of the study all areas were composed of pure stands of the respective grasses and counts were taken to determine species invasion in the fall of 1986 and 1987.

To determine thatch accumulation three plugs chosen at random were removed from each plot using an 18 mm diameter soil probe and measured. Thatch thickness of each plot was reported as the mean of the three thatch measurements.

The thatch measurements and species invasion counts were subjected to an analysis of variance and where significant differences occurred the means were separated using a LSD.

Results and Discussion

The results of the analysis of variance of thatch accumulation are shown in Table 15.

In 1986 species type was the only significant factor in thatch accumulation. Annual bluegrass had significantly less thatch than the Penncross or Penneagle creeping bentgrasses. There was however no significant difference between the creeping bentgrasses. This result was not unexpected and demonstrates the different growth habits of the two species, creeping bentgrass being an aggressive stolon producer while annual bluegrass is only weakly stoloniferous (2,9,20).

In 1987 the main effects of species, nitrogen, cultivation, and the interaction of species and nitrogen were significant.

In 1987 annual bluegrass again had significantly less thatch than either Penncross or Penneagle creeping bentgrasses with no significant difference in thatch occurring between Penncross and Penneagle (Table 16). Penncross and Penneagle both had significant increases when thatch accumulation in 1987 was compared to thatch accumulation of 1986 (Table 16). Penneagle had the greatest increase in thatch with 3.1 mm. While the difference

Table 15. Analysis of variance of the influence of species (cultivar), nitrogen, and cultivation treatment on thatch development in annual bluegrass and Penncross and Penneagle creeping bentgrass.

Main Effects	df	1986	1987	CHANGE
Species (S)	2	**	**	**
Nitrogen (N)	2	NS	*	NS
Cultivation (C)	4	NS	**	NS
Interactions				
S X N	4	NS	*	NS
S X C	8	NS	NS	NS
N X C	8	NS	NS	NS
S X C X N	16	NS	NS	NS

*, **, and NS indicates significance at p= 0.05, 0.01, and not significant respectively

Table 16. Main effect means of species on thatch accumulation for annual bluegrass, Penncross, and Penneagle creeping bentgrass for 1986,1987, and the difference between years averaged over cultivation and nitrogen treatments.

	1986	1987	Difference
.... Species	........Thatch thickness	(mm)........	
Annual bluegrass	0.79	0.72	-0.07
Penneagle	1.46	1.77	0.31
Penncross	1.46	1.71	0.25
LSD (0.05)	0.10	0.10	0.22

between the Penneagle and Penncross was not significant Penncross usually produces more thatch (1). The study reported here had minimal traffic which may have contributed to Penneagle having more thatch accumulation.

Cultivation was also determined to have an highly significant effect on thatch accumulation during 1987 and the results are summarized in Table 17.

The vertical mowing treatment resulted in significantly less thatch accumulation when compared to coring in the fall, coring in the spring and fall, and no cultivation. However, there was not a significant difference between vertical mowing and coring in the spring. Coring in the spring was not significantly different from any of the other cultivation treatments at $p=0.05$. Vertical mowing may have resulted in severing the stolons and causing the bentgrass to grow more upright preventing additional stolons from forming, which are more resistant to decay (10).

In 1987 there was also a significant species by nitrogen interaction on thatch accumulation (Table 18). Penncross had significantly less thatch when fertilized at 293 kg N ha^{-1} yr^{-1} while no differences in thatch accumulation resulted from different rates of N for the Penneagle or the annual bluegrass .

The analysis of variance of plant counts of Penncross and Penneagle taken in the fall of 1986 (Table 19) indicates

Table 17. Main effect means of cultivation treatment on thatch accumulation averaged over species and nitrogen for the 1987 season.

Cultivation treatment	Thatch thickness (mm)
No cultivation	1.51
Coring fall	1.44
Coring spring and fall	1.42
Core spring	1.37
Vertical mowing	1.28
LSD (0.05)	0.12

Table 18. Means for the interaction between species and nitrogen on thatch accumulation during 1987 for annual bluegrass, Penncross and Penneagle creeping bentgrasses averaged over cultivation treatment.

N Rate	Species			
(kg ha^{-1} yr^{-1})	A.B.	Penncross	Penneagle	LSD_b
97	0.69	1.79	1.80	0.28
195	0.69	1.81	1.84	0.28
293	0.77	1.55	1.68	0.28
LSD_a	0.17	0.17	0.17	

LSD_a value for comparison of same species or columns at p=0.05.

LSD_b value for comparison of same N rates or row at p=0.05.

that species (cultivar) was the only factor which significantly influenced the amount of annual bluegrass invasion. The plant counts indicated that Penneagle had significantly more annual bluegrass invasion (10.4%) than Penncross (6.1%).

The analysis of variance for plant counts taken in the fall of 1987 (Table 19) indicates that cultivation resulted in a significant difference in annual bluegrass invasion. Vertical mowing resulted in significantly more annual bluegrass invasion than where no cultivation was performed (Table 20). This result was similar to that reported by Youngner (23) who found that vertical mowing of bermudagrass to control thatch resulted in severe annual bluegrass invasion. While vertical mowing resulted in the greatest annual bluegrass invasion vertical mowing was not significantly different from any of the other cultivation treatments

The percent change in annual bluegrass invasion between 1986 and 1987 was also determined and the results of the analysis of variance are presented in Table 19. The analysis of variance of the percent change in annual bluegrass invasion indicates that nitrogen had a highly significant effect on the increase of annual bluegrass invasion. Increasing nitrogen rate caused an an increase in annual bluegrass invasion into creeping bentgrass with the 293 kg N ha^{-1} yr^{-1} rate resulting in significantly more annual

Table 19. Analysis of variance of Species (cultivar), nitrogen, and cultivation treatment on the invasion of annual bluegrass into Penncross and Penneagle creeping bentgrass.

Main Effects	df	1986	1987	CHANGE
Species (S)	1	*	NS	NS
Nitrogen (N)	2	NS	NS	**
Cultivation (C)	4	NS	*	NS
Interactions				
S X N	2	NS	NS	NS
S X C	4	NS	NS	NS
N X C	8	NS	NS	NS
S X C X N	8	NS	NS	NS

*, **, and NS indicates significance at p= 0.05, 0.01, and not significant respectively

Table 20. Main effects means for cultivation treatment on the invasion of annual bluegrass into Penncross and Penneagle creeping bentgrasses averaged over species (cultivar) and nitrogen.

Cultivation treatment	1986	1987	% CHANGE
	........%	invasion.........	
Vertical mowing	10.1	16.7	6.6
Core spring	10.3	12.7	2.4
Coring fall	8.1	12.3	4.2
Coring spring and fall	7.1	11.8	4.7
No cultivation	5.6	8.0	2.5
LSD (0.05)	NS	5.0	NS

Table 21. Effect of nitrogen on annual bluegrass invasion into creeping bentgrass for the years 1986, 1987, and the percent change in annual bluegrass from 1986 to 1987 averaged over species (cultivar) and cultivation.

RATE	1986	1987	CHANGE
$kg\ ha^{-1} yr^{-1}$	....	% INVASION	....
97	8.3	9.7	1.4
195	9.1	12.6	3.5
293	7.4	14.7	7.3
$LSD_{(0.05)}$	NS	NS	3.1

Table 22. Main effects of cultivation on the invasion of creeping bentgrass into annual bluegrass for 1986, 1987, and the percent change in creeping bentgrass invasion between 1986 and 1987.

Cultivation treatment	1986	1987	% CHANGE
	....	cm	....
No cultivation	0.0	1.0	1.0
Coring spring and fall	0.5	3.0	2.5
Coring fall	0.5	1.4	0.9
Vertical mowing	0.7	1.3	0.6
Core spring	3.9	4.3	0.4
LSD (0.05)	2.4	NS	NS

bluegrass invasion than 97 or 195 kg N ha^{-1} yr^{-1} rates (Table 21). The data in Table 21 also show that while some of the differences are not significant additional nitrogen fertilization usually resulted in a trend towards greater annual bluegrass invasion.

Plant counts taken in 1986 and 1987 to determine the percent creeping bentgrass invasion into annual bluegrass indicate that cultivation treatment was the only significant factor to influence creeping bentgrass invasion into annual bluegrass, and was significant only in 1986 . Coring in the spring resulted in greater creeping bentgrass invasion than any of the other treatments (Table 22). Cores and stolons may have gotten transported to the annual bluegrass plots on equipment and coring in the spring may have opened up the soil enough for establishment to occur (4). It is also possible that some creeping bentgrass may have been present when the study was initiated. However, the annual bluegrass, being a mature stand, forms a dense enough stand so that in 1987 none of the factors studied significantly influenced creeping bentgrass invasion into annual bluegrass.

To summarize the results of this investigation annual bluegrass had less thatch than Penncross or Penneagle creeping bentgrass. However, there was no difference in thatch accumulation between the two bentgrasses over the two years of this study. Vertical mowing and coring in the spring were found to reduce thatch accumulation in both bentgrasses. Nitrogen rate was found to have an effect on thatch accumulation for Penncross but not Penneagle or annual bluegrass. Application of 293 kg N ha^{-1} yr^{-1} to Penncross resulted in significantly less thatch than when Penncross was fertilized with 97 or 195 kg N ha^{-1} yr^{-1}. The 97 and 195 kg N ha^{-1} yr^{-1} rates may have resulted in increased shoot growth, shoot density, and stolon production while, when fertilized at 293 kg N ha^{-1} yr^{-1} Penncross may have had increased shoot growth but not increased shoot density or stolon production.

After the first year annual bluegrass was able to compete through either by production of allelo-chemicals or by outright competition to prevent any significant creeping bentgrass invasion (3). Invasion of annual bluegrass was significantly greater in the Penneagle (10.4%) than the Penncross (6.1%) in 1986, but was not significant in 1987 or in the percent change in annual bluegrass.

Cultivation was found to influence annual bluegrass invasion only in 1987 with vertical mowing resulting in the greatest annual bluegrass invasion. There were no significant interactions affecting annual bluegrass invasion into Penncross or Penneagle. However, it is interesting to note that for both years Penneagle had greater annual bluegrass invasion than the Penncross and that for both species vertical mowing and coring in the spring resulted in the greatest annual bluegrass invasion. This contradicts the information presented by Gibeault who reported that coring in the spring resulted in less annual bluegrass invasion (9).

Nitrogen rate resulted in significant differences in the percent change in annual bluegrass. Fertilizing with the high N rate (293 kg N ha^{-1} yr^{-1}) resulted in greater annual bluegrass invasion than the two lower rates. It is also interesting to note that in a period of two years annual bluegrass increased from less than 5% in both cultivars to 10 and 15% for the Penncross and Penneagle and is an indication of how aggressive annual bluegrass is as a weed and the need for methods of controlling it, if monostands of bentgrass are to be maintained.

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CHAPTER FOUR

A comparison of two methods for determining root growth in turf

Introduction

To understand the growth of turfgrass, knowledge of the above and below ground portions of the plant is necessary. The study of shoot growth is usually unhampered and straight forward, however the study of root systems is often difficult and hampered by the soil matrix. The study of the root system is essential for understanding water and nutrient absorption and movement (14). The root system also provides the important function of anchorage for the plant (2).

Many methods have been employed for the study of root growth (4,5,9,11,14,21,22). Bohm *et al.* (4) conducted an investigation comparing five methods of root observation commonly used to characterize root growth. From this investigation it was concluded that each method has advantages and disadvantages and the criteria for each experiment will dictate which method of observation is best.

Root weights are commonly used to quantitate root growth, but according to Reicosky (12) root absorption is more directly related to surface area or total root length.

Newman (10) developed the line intersect method of estimating root length. This method requires that roots are arranged randomly in the field of view of a microscope, in which lines have been etched on the eyepiece. Root length is estimated by the number of roots intersecting the lines etched on the microscope eyepiece in the area of view. It was determined that when the line intersect method was compared with direct root measurement the line intersect method was much quicker and yielded the same results (10). Newman also found that the line intersect method had three other advantages: 1) examination through a microscope permitted more accurate identification of root material from debris, 2) root length could be characterized by different criteria such as the length of suberized roots, the length of one species of roots compared to the root length of another species, and 3) diameter measurements could be made.

Reicosky *et al.* (12) examined three methods of determining root length which he termed the direct measurement method, the inch counter method, and the Newman line intersect method. This study determined that each method gave approximately the same root lengths as indicated by comparing the coefficients of variations of each method examined.

Marsh (7) modified Newmans line intersect method by placing a grid beneath the roots and counting each root that intersected one of the lines of the grid, instead of using the microscope with the etched eyepiece. The modification negated any need for arrangement of the roots except to reduce the concentration of roots near the wall of the container and to make counting easier. It was found that if the grid used for root counting had 100 or 1000 intersections it resulted in estimates within 3 and 0.3% of the non-modified line intersect method. The modified line intersect method developed by Marsh (7) was tested by Tennent (17) who achieved results similar to results reported by Newman (10) and Reicosky (17).

Observation of root growth of the same plant over time can only be accomplished if the method of study is non-destructive (16). Most methods used in the past to study roots are destructive and prevent any long term root investigations. Rhizotrons are underground root observation laboratories that provide one method where repeated observation and measurement of the same root system over time is possible. Rhizotrons also allow quantitative measurements of root density and changes in size and activity of root systems (8).

Taylor and Bohm (16) found that in rhizotrons root concentrations were greater along the back wall and front acrylic window than in the bulk soil. However, there were no observable visual morphological differences in the roots from the bulk soil and from along the acrylic window. Taylor and Bohm suggest that plastic windows would be acceptable where descriptive experiments were conducted, and that glass windows should be used where root density studies are to be performed. A further limitation to the use of rhizotrons is the expense involved with the construction and maintenance of the rhizotron (8).

The development of minirhizotrons by Bates (1) offered a non-destructive method of root observation in the field. Using an electric bulb and a mirror Bates was able to make preliminary observations of *Lolium perenne* L. roots.

Waddington (22) used fiber optics as a light source in the minirhizotrons and a right angle mirror in the study of wheat roots. The minirhizotron was found to provide good estimates of root size, root growth, and root penetration without disturbing the root system. However, it was also determined that adequate root resolution occurred only when the roots were greater than 0.2 mm in diameter and that the fiber optic light produced bright spots of light which were reflected off the light guide and prevented good photographs of root growth from being taken (22).

An experiment by Bohm *et al.* (4) found that when compared to other methods, minirhizotrons did not provide adequate estimations of root density but, would be very useful in phenological studies.

Sanders and Brown used a duodenoscope, used in medicine, for observation and photography of soybean (*Glycine max* L.) roots *in situ* (13). They compared root length as determined from photographs of soybean roots taken from minirhizotron tubes with root lengths taken from core samples. They found that use of minirhizotrons and the duodenoscope had several advantages: 1) it provided root measurements in a non-destructive manner with minimal soil disturbance permitting root observation throughout the growing season, 2) the minirhizotron and duodenoscope can be used at various depths and in different soil types, 3) observations can be recorded with either a 35mm camera or an 8mm movie camera, and 4) considerable time was saved using the minirhizotron and duodenscope system compared to the core sample technique.

Saunders and Brown reported that it took approximately eight person hours to process and record data for one core sample compared to 0.8 person hours for the minirhizotron and duodenscope method (13). Bohm *et al* (4) found that the time required for each sample ranged between 40 minutes for the minirhizotron method to 26 person hours for the framed monolith method.

Experiments were conducted to compare different minirhizotron orientations and to determine if root length densities (RLD) determined from pictures taken with a video camera correlated with RLD determined from core samples (18). A 13 mm diameter borescope, a low light monochrome video camera, and a video tape recorder were combined to make the minirhizotron observations. It was determined that no single minirhizotron orientation was best. It was also determined that in *Sorghum bicolor* L. a linear relationship existed between minirhizotron RLD and core sample RLD. The closeness of the relationship depended on whether means or individual values were used and what portion of the soil profile was examined. The correlation was reduced when the top 20 cm of the soil profile was included (18). Upchurch and Ritchie also found that considerable variability existed between individual minirhizotron tubes and that there was poor correlation between individual minirhizotron tube RLD and individual bulk soil RLD. It was reported that in order to estimate the rooting pattern of crops several tubes must be averaged.

The minirhizotron system previously described by Upchurch and Ritchie (18) was modified to include a small color camera and an optics system which could easily be carried into the field (19). Use of the color video camera made it easier to distinguish between old and new roots and to identify smaller diameter roots.

Upchurch (20) reported that four methods have been used to quantify the intersection of roots with the minirhizotron tube: 1) hand drawn pictures, 2) measuring the length in which the root is in contact with the tube, 3) counting the number of roots growing against the tube that cross a given mark on the tube, and 4) counting the number of roots in contact with the tube in a given area.

Root length density is the parameter most often reported in studies utilizing minirhizotrons (20). Three methods have been employed for converting root observations from minirhizotron tubes into RLD's : 1) derivation of empirical relationships between RLD measured by other techniques and root tube intersections, 2) determining the length of roots in contact with the tube and the volume of soil the roots occupy, and 3) use of theoretical conversion factors (20).

The use of minirhizotrons in turfgrass has been limited (3). Bland and Dugas (3) report that large discrepancies exist for converting minirhizotron observations to RLD for grasses.

It has also been reported that poor correlations exist between bulk soil RLD and RLD determined from the top 20 cm of the soil (6,18,19). In turfgrass the top 20 cm is the most important region of root growth. It is very important to determine if minirhizotrons can be used to quantitate root number in turfgrasses. The objective of this experiment was to determine if root counts obtained from minirhizotron video tapes of turfgrass roots would correlate with RLD determined from turfgrass core samples.

Material and Methods

Research was conducted on annual bluegrass (*Poa annua* var. *reptans* Hausknn. (Timm.)) and Penncross creeping bentgrass (*Agrostis palustris* cv. `Penncross´ Huds.) turfs. Thirty six minirhizotron tubes, clear polybutyrate tubes 51 mm ID X 91 cm with 3.2 mm walls, were inserted into an Owosso-Marlette sandy loam complex (fine-loamy, mixed, mesic Typic and Glossoboric Hapludalfs) soil. The minirhizotrons were inserted into the soil at a 30 degree angle to the soil surface. Installation of the minirhizotrons consisted of boring holes into the soil with a modified hydraulic soil sampling probe (Giddings Model GSRP-ST). The probe was equipped with a boring tip designed to keep soil compaction around the tube to a minimum. Following boring a wire brush was inserted into the tube hole and rotated as it was moved up and down, to minimize any striations or channels which may have formed. Prior to placing the minirhizotron tubes into the holes the top and the bottom of the minirhizotron tube were capped with number 11 rubber stoppers. Insertion of the minirhizotron tubes was done by pushing the tubes into the hole by hand, making every attempt to keep good contact between the tube and the soil. The portion of the minirhizotron tube which protruded above the turf was first painted black to exclude any light penetration then painted white to reduce solar heating.

Three minirhizotron tubes were inserted into each of six plots in each species. Both species were maintained at 13 mm height of cut (bench setting) using a triplex mower. Irrigation and fungicides were applied as needed. Clippings were removed from the creeping bentgrass plots and returned to the annual bluegrass plots. The grass was trimmed to 13 mm around each tube using hand clippers. Nitrogen fertilizer was applied monthly to both species at a rate of 24 kg ha^{-1}.

Minirhizotron data was collected by inserting a microvideo camera system (Circon Model MV-9011 Agricultural Camera) into each tube. Video images of roots were recorded using a portable video cassette recorder (Panasonic Model NV-8420) and a portable computer to record the tube number, date, and depth of the first root. Minirhizotron video data collection was initiated on 1 June 1987 and continued at two week intervals throughout the remainder of the growing season. Video taping started at the deepest point of root penetration and proceeded upwards in increments of 12 mm. Root images were later counted on a color monitor from video tapes recorded 10 July and 30 September 1987. Root counts from minirhizotron VCR tapes were determined by counting the number of roots from each frame and then summing four consecutive frames which corresponded to approximately 2.5 cm depth increment.

Core samples were collected on 28 September 1987. Core samples were obtained by driving a 5.1 X 5.1 X 30 cm (L x W x D) core sampler into the ground with a rubber mallet which minimized compaction of the core sample. Three core samples were taken from each plot and subdivided into section corresponding to the following depths from the surface 0-3, 3-5, 5-8, 8-15, 15-23, and 23-30 cm. Each section of core sample was washed using the hydropneumatic elutriation system developed by Smucker *et al.* (15) to remove the soil particles. Washed roots were stored in water in a cold room until RLD's were determined using the modified Newmans line intersect method (7).

Data was analyzed by conducting linear regression analysis. The RLD of the core samples at each depth was the independent variable and the minirhizotron root count at each depth was the dependent variable. Regression analysis was conducted at each depth, for both species, and for each sampling date. Differences between July and September minirhizotron VCR root counts were subjected to an analysis of variance to determine if differences between sampling dates were significant.

RESULTS AND DISCUSSION

The results of regression analysis comparing RLD determined from core samples and root counts taken from minirhizotron VCR video tapes are presented in Tables 23 and 24. Table 23 summarizes the results of regression analysis conducted on the two methods in annual bluegrass, and indicates that a significant correlation between core sample RLD and minirhizotron root counts occurred at only one depth (15-23 cm). Significant correlations occurred between core sample RLD and minirhizotron root counts in the creeping bentgrass for the upper three sampling depths (0-3, 3-5, and 5-8 cm) (Table 24). Below 8 cm no significant correlation between the two methods occurred. The results of the regression analysis for the comparison of the two methods in creeping bentgrass for September were different than the results that Upchurch and Ritchie (18) reported for *Sorghum bicolor* L.. They found that correlations between core sample RLD and minirhizotron root RLD improved below 20 cm. The inconsistent correlations between the two methods of studying the roots of annual bluegrass and creeping bentgrass, that occurred in this investigation were similar to results reported by other researchers studying other crops (3,6,18).

Table 23. Results of regression analysis comparing root growth estimates in annual bluegrass determined by root length density from core samples taken 28 September and root counts determined from minirhizotron VCR tapes recorded 30 September 1987. (N=18)

DEPTH	CORES	VCR TAPE	
-cm-	-RLD[x] -	-#[y] -	--r--
0-3	2922	59	-0.01 NS
3-5	1464	27	0.00 NS
5-8	501	7	0.04 NS
8-15	528	5	-0.24 NS
15-23	226	3	0.55 *
23-30	98	1	0.13 NS

*,NS indicates significance at p=0.05 and not significant
x represents the number of roots which come into contact with a grid with 4 cm centers at the given depth.
y represents the number of roots counted from minirhizotron VCR tapes at the given depth.

TABLE 24. Results of regression analysis comparing root growth estimates in creeping bentgrass determined by root length density from core samples taken 28 September and root counts determined from minirhizotron VCR tapes recorded 30 September 1987. (N=18)

DEPTH	CORES	VCR TAPE	
-cm-	-RLD[x] -	-#[y] -	--r--
0-3	5107	182	-0.52*
3-5	2544	130	0.52*
5-8	1590	80	0.50*
8-15	2719	148	0.35NS
15-23	1625	89	0.21NS
23-30	1400	35	0.09NS

*,NS indicates significance at p=0.05 and not significant
x represents the number of roots which come into contact with a grid with 4 cm centers at the given depth.
y represents the number of roots counted from minirhizotron VCR tapes at the given depth.

Although quantification of absolute root number using minirhizotrons in turf needs more examination, minirhizotrons still offer a good method of making non-destructive comparisons of root growth at different times of the growing season. The usefulness of minirhizotrons for comparing root growth over time is demonstrated in Figures 1 and 2, which compare minirhizotron root counts taken in July and September for both species. Figure 1 compares minirhizotron counts between July and September for creeping bentgrass and indicates that significantly fewer roots were present in September at the 5-8 cm depth than in July.

Comparison of annual bluegrass root counts determined from minirhizotron VCR tapes taken in July and September (Fig. 2) indicates that there were significantly fewer roots present in September than in July at all depths except the 23-30 cm depth where there was no significant difference.

A second advantage that root counts from minirhizotron VCR tapes have, when compared to RLD determined from core samples, is the difference in time required for processing and collection of data. In annual bluegrass and creeping bentgrass, where a majority of the roots are found in the upper 20 cm of the soil profile, it took approximately 10 hours to collect, wash, and count each 30 cm core sample. It took approximately 0.75 hour to record and count the roots to similar depth from a minirhizotron VCR tape . The savings in time and labor will allow for greater number of

Figure 1. Comparison of root counts at various depths determined from minirhizotron VCR tapes recorded 10 July and 30 September for creeping bentgrass turf. (Comparisons at each depth for each date are averaged over 18 samples.)

FIGURE 1. CREEPING BENTGRASS

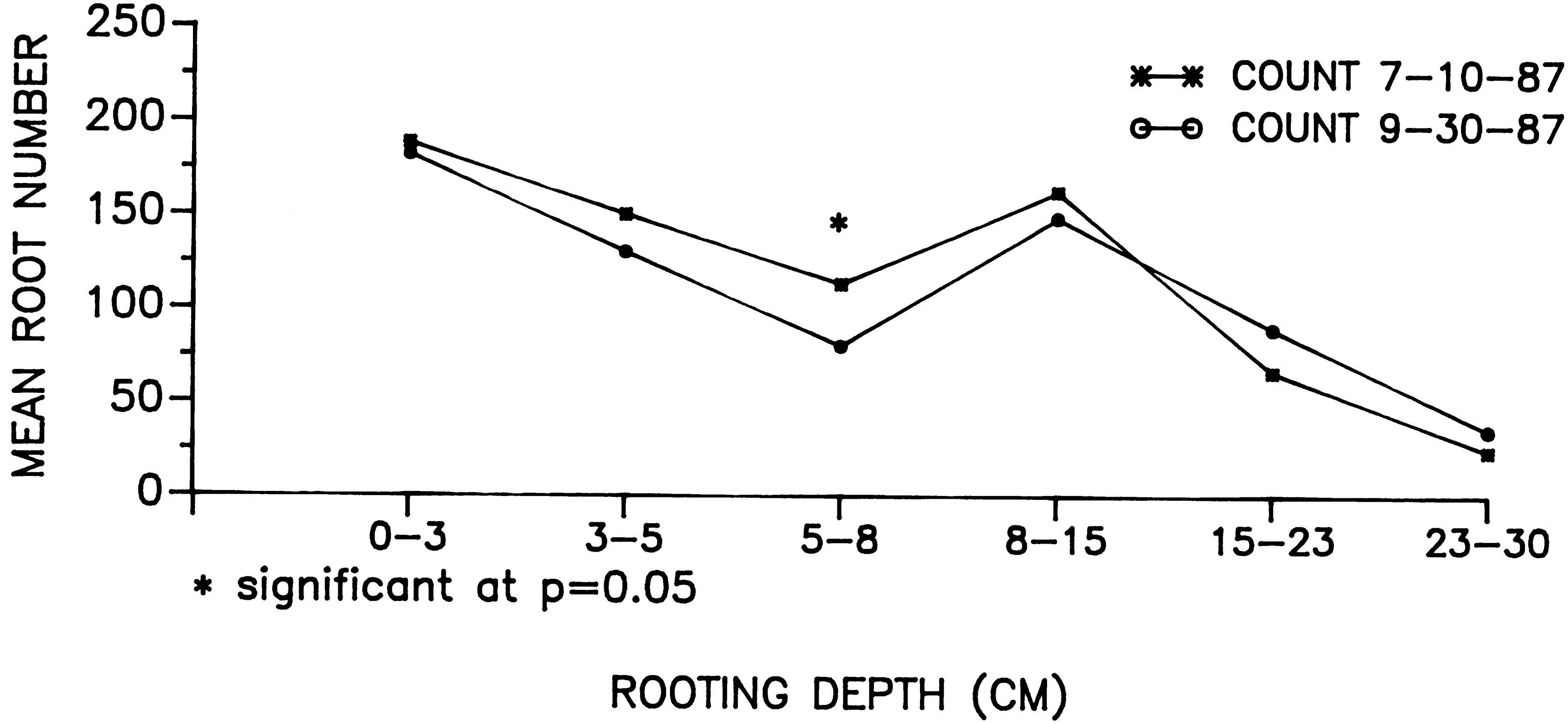
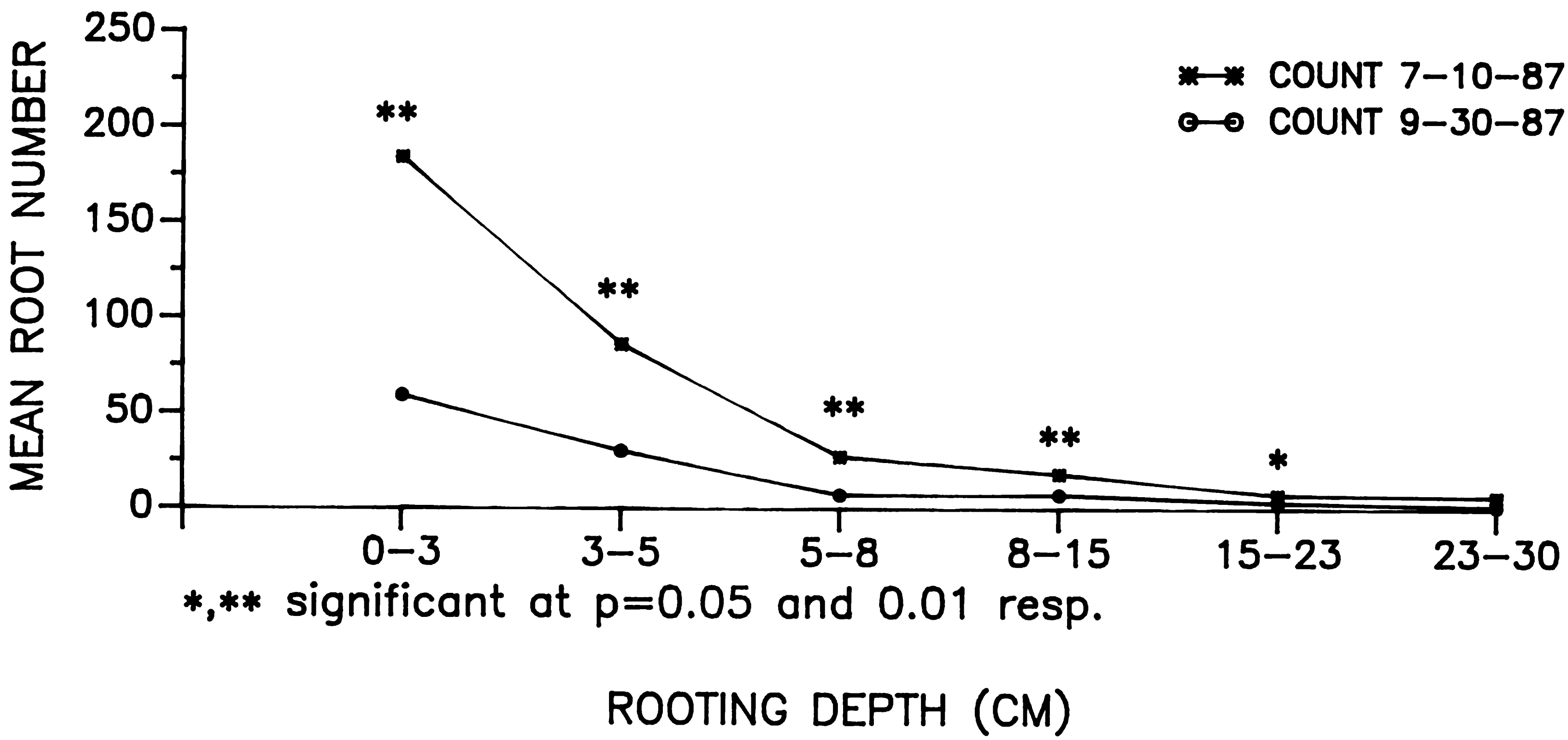


Figure 2. Comparison of root counts at various depths determined from minirhizotron VCR tapes recorded 10 July and 30 September for annual bluegrass turf. (Comparisons at each depth for each date are averaged over 18 samples.)

FIGURE 2. ANNUAL BLUEGRASS



samples to be taken. The time it took to collect and process the core samples and minirhizotron tapes in turf was similar to the time reported by other researchers (4,13).

To summarize the results of this experiment use of minirhizotrons in turf to determine the precise number of roots present in a given soil profile needs more examination. However, minirhizotrons do provide an excellent method for examining the effects on root growth from fertilizers, environmental stress, compaction, or other factors with influence plant growth.

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APPENDIX

APPENDIX Table 1 Raw data for the comparison of two methods of studying root growth in turfgrass.

LIST OF VARIABLES

VAR	TYPE	NAME/DESCRIPTION
1	numeric	REPLICATION
2	numeric	SUB-SAMPLE NUMBER (1=A 2=B 3=C)
3	numeric	DEPTH (1=0-3, 2=3-5, 3=5-8, 4=8-15, 5=15-23, 6=23-30 cm)
4	numeric	ROOT COUNTS FROM SECOND CORE SAMPLE TAKEN 28 SEPTEMBER 1987
5	numeric	ROOT COUNTS FROM 30 SEPTEMBER 1987 VCR TAPE

CASE NO.	1	2	3	4	5
1	101	1	1	3960	51
2	101	2	1	3856	55
3	101	3	1	2985	33
4	102	1	1	3397	33
5	102	2	1	3097	39
6	102	3	1	3836	61
7	103	2	1	2999	26
8	103	3	1	3174	101
9	103	1	1	3303	71
10	104	1	1	3096	63
11	104	2	1	2013	52
12	104	3	1	1359	67
13	105	3	1	3041	65
14	105	1	1	3341	110
15	105	2	1	3486	54
16	106	1	1	1471	38
17	106	2	1	2397	68
18	106	3	1	1782	83
19	107	3	1	6126	112
20	107	1	1	5989	190
21	107	2	1	5827	126
22	108	1	1	6140	170
23	108	2	1	5632	170
24	108	3	1	6086	115
25	109	2	1	5848	220
26	109	1	1	5197	200
27	109	3	1	5551	195
28	110	3	1	5373	190
29	110	1	1	291	220
30	110	2	1	5642	195
31	111	2	1	4972	195

Appedix Table 1 con't.

CASE NO.	1	2	3	4	5
32	111	1	1	5188	175
33	111	3	1	4066	205
34	112	2	1	4371	210
35	112	3	1	5248	165
36	112	1	1	4371	215
37	101	2	2	1208	18
38	101	3	2	1500	5
39	101	1	2	1082	30
40	102	3	2	1440	35
41	102	1	2	1440	10
42	102	2	2	8004	27
43	103	1	2	966	10
44	103	2	2	544	24
45	103	3	2	1024	29
46	104	1	2	909	18
47	104	2	2	1224	6
48	104	3	2	588	38
49	105	1	2	1181	96
50	105	2	2	991	38
51	105	3	2	1245	43
52	106	2	2	980	7
53	106	3	2	1072	39
54	106	1	2	953	4
55	107	3	2	2357	124
56	107	1	2	2595	161
57	107	2	2	3195	105
58	108	1	2	2972	180
59	108	2	2	2551	175
60	108	3	2	2697	92
61	109	2	2	3083	160
62	109	1	2	3054	155
63	109	3	2	2328	160
64	110	1	2	2531	142
65	110	2	2	2814	125
66	110	3	2	2347	43
67	111	3	2	3077	184
68	111	2	2	2467	140
69	111	1	2	1982	125
70	112	1	2	2041	118
71	112	2	2	1842	64
72	112	3	2	1862	85
73	101	2	3	597	5
74	101	3	3	687	0
75	101	1	3	330	5
76	102	1	3	568	2
77	102	2	3	357	0

Appendix Table 1 con´t.

CASE NO.	1	2	3	4	5
78	102	3	3	828	15
79	103	2	3	580	1
80	103	3	3	380	6
81	103	1	3	421	0
82	104	1	3	719	10
83	104	2	3	421	7
84	104	3	3	128	7
85	105	1	3	295	41
86	105	2	3	458	14
87	105	3	3	1167	13
88	106	2	3	290	4
89	106	3	3	435	3
90	106	1	3	359	0
91	107	1	3	1546	72
92	107	2	3	1470	72
93	107	3	3	1569	76
94	108	3	3	1524	67
95	108	1	3	2067	123
96	108	2	3	1691	95
97	109	1	3	1993	70
98	109	2	3	1394	150
99	109	3	3	1901	104
100	110	3	3	1652	70
101	110	1	3	1704	88
102	110	2	3	1433	63
103	111	1	3	1311	45
104	111	2	3	1566	44
105	111	3	3	1963	123
106	112	2	3	1066	59
107	112	1	3	1247	52
108	112	3	3	1514	72
109	101	1	4	455	5
110	101	3	4	762	0
111	101	2	4	590	2
112	102	1	4	390	11
113	102	2	4	516	0
114	102	3	4	618	4
115	103	2	4	934	5
116	103	3	4	168	4
117	103	1	4	678	0
118	104	1	4	540	2
119	104	2	4	446	14
120	104	3	4	191	5
121	105	2	4	870	6
122	105	3	4	640	1
123	105	1	4	389	19

Appendix Table 1 con´t.

CASE NO.	1	2	3	4	5
124	106	1	4	347	0
125	106	2	4	436	4
126	106	3	4	535	7
127	107	3	4	2385	177
128	107	1	4	2004	90
129	107	2	4	2703	99
130	108	1	4	2924	153
131	108	2	4	2434	123
132	108	3	4	1534	94
133	109	1	4	3523	172
134	109	2	4	3684	162
135	109	3	4	2509	137
136	110	3	4	1856	192
137	110	1	4	3276	170
138	110	2	4	2688	116
139	111	1	4	2727	278
140	111	2	4	3065	217
141	111	3	4	3618	194
142	112	3	4	2912	124
143	112	1	4	2210	103
144	112	2	4	2886	69
145	101	1	5	148	0
146	101	2	5	222	0
147	101	3	5	242	0
148	102	3	5	204	0
149	102	2	5	158	0
150	102	1	5	898	15
151	103	1	5	191	0
152	103	2	5	232	0
153	103	3	5	232	0
154	104	1	5	188	0
155	104	3	5	92	0
156	104	2	5	202	0
157	105	1	5	129	9
158	105	2	5	201	16
159	105	3	5	214	0
160	106	2	5	237	0
161	106	3	5	140	9
162	106	1	5	133	0
163	107	3	5	1693	202
164	107	1	5	1793	11
165	107	2	5	1336	46
166	108	1	5	1948	187
167	108	2	5	1663	103
168	108	3	5	1390	36
169	109	1	5	1418	112

Appendix Table 1 con´t.

CASE NO.	1	2	3	4	5
170	109	2	5	1918	78
171	109	3	5	1550	105
172	110	1	5	1308	102
173	110	2	5	1835	87
174	110	3	5	1680	90
175	111	2	5	2106	98
176	111	3	5	2508	64
177	111	1	5	1424	115
178	112	3	5	1433	104
179	112	1	5	1348	32
180	112	2	5	895	38
181	101	3	6	87	0
182	101	1	6	61	0
183	101	2	6	5	0
184	102	1	6	366	2
185	102	3	6	55	0
186	102	2	6	4	0
187	103	2	6	162	0
188	103	3	6	106	0
189	103	1	6	117	0
190	104	1	6	106	0
191	104	3	6	48	0
192	104	2	6	47	0
193	105	1	6	88	9
194	105	2	6	71	0
195	105	3	6	136	0
196	106	2	6	90	0
197	106	3	6	98	7
198	106	1	6	44	0
199	107	1	6	831	6
200	107	2	6	769	0
201	107	3	6	1037	53
202	108	2	6	352	51
203	108	3	6	652	0
204	108	1	6	774	0
205	109	1	6	781	91
206	109	2	6	980	22
207	109	3	6	1203	47
208	110	3	6	530	7
209	110	1	6	710	131
210	110	2	6	806	48
211	111	1	6	844	49
212	111	2	6	887	1
213	111	3	6	1167	56
214	112	1	6	484	35
215	112	2	6	930	14
216	112	3	6	625	10