RESEARCH SUB-PROGRAM

THE EFFECTS OF LIVESTOCK MANURE APPLICATION METHODS ON WATER QUALITY, FOCUSING ON NITROGEN AND BACTERIA TRANSPORT IN SOIL

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FORWARD

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agri-Food Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
   - **A.** Animal Manure Management (nutrients and bacteria)
   - **B.** Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

The original level of funding for the research component was $9,700,000 through Mar. 31, 1997. Projects will be carried out by Agriculture and Agri-Food Canada, universities, colleges or private sector agencies including farm groups.

This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

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Final Report

RES/MAN-005/97

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1.0) EXECUTIVE SUMMARY

In a joint effort between Agriculture and Agri-Food Canada, the Upper Thames River Conservation Authority and the Ontario Ministry of Agriculture Food, and Rural Affairs, a study was conducted with the following objectives:

1) Conduct field scale studies of liquid manure application technologies for different soil/climatic conditions;
2) Evaluate application technologies in no-till corn cropping systems in terms of sustainable crop productivity and subsurface water quality (nitrogen, bacteria);
3) Identify pathways and processes of nutrient and bacteria transport to tile drains and ground water with special consideration to preferential flow;
4) Validate tile drainage water quality model (DRAINMOD) with field scale data and use models to identify scenarios in which water quality standards are likely exceeded;
5) Develop liquid manure application recommendations for environmentally sustainable no-till corn crop production.

Three (two ha) field sites were selected in the Mixedwood Plains ecozone with contrasting soil textures (Site 1(medium)-silt loam, Site 2 (light)- sandy loam and Site 3 (heavy)- silty clay loam), systematic tile drainage and a history of no-till corn crop management. A no-till corn crop was planted in May at each field site by the farm cooperator using commercial no-till planters outfitted with various coulter and trash whipper arrangements to manage the corn residue. Starter fertilizer was applied with the planting units according to the farm cooperators preference with rates ranging from 5-36kg N/ha, 6-14kg P/ha, and 0-26kg K/ha. Control plots were fertilized at the time of planting according to soil test recommendations. Soil and manure nutrient analysis conducted in about the 3rd week of June was used to compute the manure application rates that would be required to meet the crop N requirements according to soil test recommendations. The required liquid manure application rates ranged from about 56,165 to 71,890 L/ha. Crop performance (plant populations, time to silking, leaf tissue analysis, weed pressure, lodging, grain moisture and yield) was monitored from the time of emergence to harvest. The cost effectiveness of the manure application equipment in terms of draft and fuel consumption was measured with an instrumented research tractor from Agriculture and Agri-Food Canada.

The liquid hog manure was side dressed with a 6,800 L tanker around the fourth leaf stage by surface application and two injection techniques (conventional injection and injection modified by slight tillage in front of the injectors). Before application of the manure, bacteria tracer and strontium chloride(StCl) and potassium bromide(KBr) were added to the manure. The area being drained by each of 12 tiles (7m by 100m) was treated as an individual plot. Three treatments (surface applied, conventional injection, modified injection) and a control (inorganic fertilizer) were replicated three times, and crop and water quality response to the liquid manure application was monitored. On the day following the manure application, rainfall was simulated using a travelling gun irrigation system to apply about two to three cm of water to the plots over a 20 to 30min period.

Water quality samples were taken weekly throughout the growing season while the tiles were flowing. On the days of manure application and the simulated rainfall event, tile water quality samples were taken at 15 min to three hour intervals. An automated meterological station at each study site provided temperature, relative humidity, wind speed/direction, and 15 minute precipitation data. Soil and hydrologic data from the study sites were used to evaluate a tile flow prediction model (DRAINMOD 4.0). Two years of data were obtained for Sites 1 and 2 while a single year of data was collected at Site 3.

Agronomic results showed that the use of liquid manure at side dress did not impair performance of crop growth and development. The combination of side dressed manure N and the starter fertilizer N when applied at soil test recommended rates provided no-till corn yields that were not statistically different from the control treatments where inorganic fertilizers were used. There was also no significant difference in grain yield between the injection and surface manure application methods, although both plant populations and grain yields were marginally lower than the control plots in three of the five crop years. The tractor energy consumption data clearly showed the extra power required for the modified injection configuration over the conventional injection, however, the difference was relatively small and the modified injection configuration was considered practical from an energy consumption perspective.

Liquid manure application for all treatments resulted in increased rates of tile flow volumes within 30 minutes of application and returned to base flow conditions within three hours. Flow rate increases were greatest when the tiles were flowing prior to the manure application. The simulated rainfall event increased tile flows significantly by approximately 20L/min at Sites 1 and 2 and by 7 L/min at Site 3 and did not return to base flows for several days. Flow increases in the tile drains after liquid manure application represent less than 3% of the applied manure, while tile drain flow increases after the simulated rainfall represent about 10% of rainfall volumes at Sites 1 and 2 and less than 5% at Site 3.

Tile water quality impairment was observed through increased turbidity and measured through the presence of bacteria and ammonium, for all manure application treatments within 7 to 30 minutes of application and continued for two to three hours. While the total volume of applied manure reaching the tile was small(<2%), water quality guidelines for bacteria, ammonium and phosphorus were exceeded for several hours. The presence of the bacteria tracer and chemicals in the tile water samples after manure application provided verification that manure was the source of contamination. The simulated rainfall event resulted in increased levels (but at lower concentrations then following manure application) of ammonia, bacteria tracer and phosphorus within 30 minutes and peaked within 60 minutes. Since the bacteria and chemical tracers were not detected in the tile water a few days after the rainfall event it appears that the impact of the manure application on the tile water quality is relatively short-lived.

The movement of the tracers strontium, bromide and chloride mirrored the bacteria movement to the tile drains both in time and concentration. The percentage of the applied non-reactive tracers bromide and chloride reaching the tile drains was found to approximate the percentage of liquid manure reaching the tile drains (<2% of applied). While <1% of the applied reactive tracer (strontium) was recovered in the tile water, it provides evidence that the macropore pathways are contributing to tile flows even under the unsaturated soil moisture conditions of the experiment.

Regardless of the method of liquid manure application, tile water contamination occurred both immediately following the manure application and the simulated rainfall event. In this no-till system, it may only be possible to stop tile water contamination by applying liquid manure during the growing season periods when soil moisture content is low and tile drains are not flowing.

The tile drainage model (DRAINMOD 4.0) provided statistically good predictions of tile flow for both years at Sites 1 and 2 compared to measured flow values. Further study of the water quality components of the model that are currently under development may be warranted.

Study results have led to the following recommendations for the application of liquid manure in no-till cropping systems:

i) Liquid manure nutrient testing is required immediately prior to manure application to establish accurate manure application rates.

ii) Side dress injection or surface application, at the fourth leaf stage, of liquid manure at soil test recommended rates will produce corn yields equivalent to conventional inorganic N fertilization.

iii) Conventional and modified injection equipment tested are recommended for use on medium to light textured soils.

iv) Side dressed injection applications should be considered to reduce impacts on tile water quality relative to surface applications especially on medium and light textured soils.

v) Apply liquid manure to tile drained land when the tile drains are not flowing to reduce impacts on tile water quality.

Sommaire

Agriculture et Agroalimentaire Canada, l'Office de protection de la nature de la rivière Thames supérieure et le ministère de l'Agriculture, de l'Alimentation et des Affaires rurales de l'Ontario ont mené conjointement une étude qui visait les objectifs suivants :

1) effectuer des études sur le terrain de technologies d'épandage de purin dans différentes conditions pédologiques et atmosphériques;
2) évaluer des technologies d'épandage dans des systèmes de culture du maïs sans travail du sol, des points de vue de la productivité durable des cultures et de la qualité des eaux souterraines (azote, bactéries);
3) déterminer les voies et les processus de transport des substances nutritives et des bactéries jusqu'aux tuyaux de drainage et aux eaux souterraines, compte tenu en particulier de l'écoulement préférentiel;
4) valider un modèle de qualité de l'eau de drainage souterrain (DRAINMOD) à l'aide de données de terrain et utiliser des modèles pour élaborer des scénarios dans lesquels la qualité de l'eau dépasse vraisemblablement les normes de qualité;
5) formuler des recommandations concernant l'épandage du purin pour la production de maïs sans travail du sol et de façon écologique.

On a choisi, dans l'écozone des plaines à forêts mixtes, trois sites de deux hectares chacun se distinguant par la texture des sols : loam moyennement limoneux au premier site (sol à texture moyenne), loam légèrement sableux au deuxième site (sol à texture légère) et fin limon fortement argileux au troisième site (sol à forte texture). Les trois sites étaient soumis à un drainage souterrain systématique et étaient déjà exploités pour la culture du maïs sans travail du sol. En mars, les agriculteurs participant à l'étude ont semé du maïs sans travail du sol aux trois endroits à l'aide de semoirs pour semis direct dotés de divers accessoires servant à la gestion des résidus de maïs. Un engrais de démarrage a été épandu au moyen des semoirs selon les préférences des agriculteurs à c taux de 5 à 36 kg d'azote par hectare, de 6 à 14 kg de phosphore par hectare et de 0 à 26 kg de potassium par hectare. De l'engrais a également été épandu dans des parcelles témoins au moment des semis, en fonction des résultats d'analyses des sols. Les résultats d'une analyse des substances nutritives des sols et des fumiers effectuée à peu près pendant la troisième semaine de juin ont servi déterminer les taux d'épandage du fumier requis pour répondre aux besoins en azote des cultures selon les résultats des analyses de sols. Les taux d'épandage de purin requis allaient d'environ 56 165 à 71 890 L/ha. Le rendement des cultures (nombre de plants, délai d'apparition des soies, analyse des feuilles, attaque des mauvaises herbes, verse, teneur en eau du grain et rendement en grains) a fa l'objet d'un suivi depuis l'émergence jusqu'à la récolte. La rentabilité de l'équipement d'épandage du fumier (déplacement et consommation de carburant) a été mesurée au moyen d'instruments embarqués sur un tracteur de recherche d'Agriculture et Agroalimentaire Canada.

Le fumier de porc liquide a été épandu en bandes latérales à partir d'une citerne d'une capacité de 6 800 L à peu près au stade d'émergence de la quatrième feuille; les méthodes employées étaient l'épandage en surface et deux méthodes d'injection (l'injection traditionnelle et l'injection avec léger travail du sol à l'avant des injecteurs). Avant l'épandage, on a ajouté au fumier des traceurs de bactéries, du chlorure de strontium (StCl) et du bromure de potassium (Kbr). La zone drainée par chacun des 12 drains (7 x 100 m) était considérée comme une parcelle. On a répété trois fois les trois traitements (épandage en surface, injection traditionnelle et injection modifiée) et un traitement témoin (épandage d'engrais inorganique), et l'effet des épandages de fumier liquide sur les cultures et la qualité de l'eau a fait l'objet d'un suivi. Le lendemain des jours des épandages, on a simulé des chutes de pluie à l'aide d'un système d'irrigation à pistolet mobile : les parcelles ont reçu quelque deux à trois centimètres d'eau sur une période de 20 à 30 minutes.

Des échantillons d'eau de drainage ont été prélevés pendant toute la saison de croissance à des fins d'évaluation de la qualité de l'eau. Les jours des épandages de fumier et de simulation des pluies, ils étaient prélevés à des intervalles allant de 15 minutes à trois heures. À chaque site, des données sur la température, l'humidité relative, la vitesse et la direction du vent et les hauteurs de précipitations aux 15 minutes étaient fournies par une station météorologique automatique. Des données pédologiques et hydrologiques recueillies à ces endroits ont servi à évaluer un modèle de prévision de l'écoulement de l'eau de drainage (DRAINMOD 4.0). Les données ont été recueillies pendant deux ans aux sites 1 et 2 et pendant un an au site 3.

Les données agronomiques ont révélé que l'épandage du fumier liquide en bandes latérales n'avait pas réduit la croissance du maïs. L'azote fourni par l'épandage du fumier en bandes latérales et de l'engrais de démarrage aux taux conformes aux résultats de analyses de sol a donné des rendements en maïs (semis directs) qui n'étaient pas différents statistiquement de ceux résultant des traitements à l'engrais inorganique dans les parcelles témoins. De même, on n'a pas décelé de différence significative dans le rendement en grains entre les méthodes d'épandage par injection et d'épandage en surface. Toutefois, le nombre de plants et les

rendements en grains étaient légèrement inférieurs à ceux observés dans les parcelles témoins pendant trois des cinq années de culture. Selon les données sur la consommation d'énergie par les tracteurs, il est évident que la méthode d'épandage par injection modifiée nécessite plus d'énergie que la méthode par injection traditionnelle; l'écart était cependant relativement faible, de sorte que la première méthode était considérée acceptable du point de vue de la consommation d'énergie.

Dans tous les cas, l'épandage de fumier liquide faisait augmenter le débit d'écoulement de l'eau de drainage dans les 30 minutes suivant l'épandage, puis celui-ci revenait à la normale dans les trois heures. L'accroissement du débit était plus important quand il coulait déjà de l'eau dans les canalisations avant l'épandage du fumier. Les pluies simulées ont produit une forte hausse du débit d'écoulement, soit d'environ 20 L/min aux sites 1 et 2 et de 7 L/min au site 3, et celui-ci n'est revenu à la normale que plusieurs jours plus tard. L'eau supplémentaire présente dans les canalisations de drainage après l'épandage du fumier liquide représentait moins de 3 % du volume du fumier liquide épandu, tandis que l'eau présente après les pluies simulées représentait environ 10 % et moins de 5 % des quantités d'eau de pluie respectivement aux sites 1 et 2 et au site 3.

On a observé une diminution de la qualité de l'eau de drainage - accroissement de la turbidité et présence de bactéries et d'ammoniac - après tous les traitements au fumier dans les 7 à 30 minutes suivant l'épandage, et cette situation a persisté pendant deux à trois heures.

Les déplacements des traceurs de bactéries, du chlorure de strontium et du bromure de potassium correspondaient à ceux des bactéries vers les canalisations de drainage, tant sur le plan temporel que sur celui des concentrations. La proportion des traceurs non réactifs, du chlorure et du bromure atteignant les canalisations était à peu près égale à la proportion de fumier liquide.

Quelle que soit la méthode d'épandage de fumier liquide employée, il s'est produit une contamination de l'eau immédiatement après les épandages de fumier et les pluies simulées. Quand on utilise un système de semis direct, la seule façon d'empêcher la contamination de l'eau de drainage pourrait consister à épandre le fumier liquide pendant les périodes de la saison de croissance où la teneur en eau du sol est faible et où il n'y a pas déjà d'écoulement d'eau dans les drains.

Le modèle de prévision de l'écoulement de l'eau de drainage (DRAINMOD 4.0) a produit des prévisions statistiquement valables du débit d'écoulement par rapport au débit mesuré pendant les deux ans de l'étude aux sites 1 et 2. Il pourrait être indiqué de pousser l'étude des composantes du modèle relatives à la qualité de l'eau qui sont en voie d'élaboration.

Les résultats de l'étude permettent de formuler les recommandations suivantes concernant l'épandage de fumier liquide dans les systèmes de culture sans travail du sol :

i) Il faudrait mesurer la teneur en substances nutritives du fumier liquide immédiatement avant l'épandage afin d'établir avec précision les taux d'épandage.
ii) L'injection en bandes latérales ou l'épandage en surface de fumier liquide, au stade d'émergence de la quatrième feuille, aux taux recommandés selon les résultats des analyses de sol, produira des rendements en maïs équivalents à ceux obtenus pa l'utilisation d'engrais à base d'azote inorganique.
iii) L'équipement d'injection traditionnelle et d'injection modifiée mis à l'essai est recommandé pour usage sur les sols à texture moyenne à légère.
iv) Il faudrait envisager la possibilité d'épandre le fumier par injection en bandes latérales plutôt que directement en surface pour réduire les effets sur la qualité de l'eau, surtout dans les sols à texture moyenne et à texture légère.
v) Là où il existe des canalisations de drainage, il faudrait épandre le fumier liquide quand il n'y a pas déjà d'écoulement d'eau afin de réduire les effets sur la qualité de l'eau.

2.0) INTRODUCTION

It is well documented that significant amounts of nitrogen and bacteria from manure applications to land can be transported both by overland flow and by vertical infiltration processes (Goss et al. 1993). When either process is active, the water quality of surface and ground water can be negatively affected. The immediate incorporation of manure into the soil as recommended in the Agriculture Code of Practice (1976) for Ontario reduces substantially the potential for surface water pollution.

Livestock production continues to be an important agricultural industry in Ontario. The Agricultural Statistics for Ontario (1987) report approximately three million swine, 0.7 million dairy cattle, 1.5 million beef cattle, and 35 million poultry. Miller et al. (1989) have computed the fertilizer replacement value of manure produced by these livestock populations to be about $158 million.

The concern for nitrogen and bacteria in water arises out of a threat to human health and wildlife habitats. Nitrate-N concerns are related primarily to infant health and in particular methaemoglobinaemia (infant cyanosis or blue baby) (Fraser and Chilvers 1981). In recognition of this problem a safe limit of 10 mg NO_3-N/L has been established for drinking water (OMOE, 1978).

While the evidence is less direct, nitrate and nitrite-N have also been linked with cancer due to the formation of nitrosamines (Fraser et al. 1980). Nitrosamines are known to be very active carcinogens in animals but there is no direct evidence linking them to human cancer. A third potential drinking water health effect from nitrates reported relates to malformations of the central nervous system and musculoskeletal system in infants (Dorsch et al. 1984). Nitrates may also be a concern for livestock health. Livestock drinking water concentrations of 20 mg NO_3-N/L is considered safe for farm use. Willoughby (1971) has reported that swine are most susceptible to nitrogen-toxicity followed by cattle, sheep and horses.

Concentration of ammonium in water is a concern for wildlife populations. Fish have been found to be highly sensitive to free ammonia in water. (Thurston et al. 1984; Thurston and Russo 1983). Toxic to chronic toxicity concentrations of un-ionized ammonia for rainbow trout have been reported at 0.02 to 0.16 mg/L respectively. Ammonium concentrations of up to

5 mg/L may be associated with manure spills while Spires and Miller (1978) report mean surface water runoff concentrations of 1.8 mg/L from manured fields.

Bacteria concentrations in surface and ground water are potential problems. Bacterial populations in manure are such that any inputs to surface or subsurface water supplies will result in bacterial contamination of the water. Baxter et al.(1988) found that fecal coliform and fecal streptococci counts are indicative of water contamination from fecal material. Ontario water quality bacteria standards for drinking and recreational use are 0 and 100 counts respectively for fecal counts (OME 1978). Waterborne pathogens (protozoans) such as Giardia and cryptosporidium paarvum that are linked to human and livestock wastes have been identified as a health concern for drinking water supplies. Recent outbreaks of these pathogens in the municipal drinking water supplies of two Ontario cities (Waterloo and Collingwood) have prompted provincial agricultural and environmental agencies to investigate potential livestock sources (personal communication with D. Hilborn, OMAFRA).

The trends toward liquid manure handling systems and conservation tillage systems in Ontario have raised questions regarding the best manure management methods to achieve maximum economic yield while preventing nitrogen and bacterial contamination of tile and ground water. Liquid manure application methods, application rates for different soils and crops, and the timing of application are among questions being asked by producers. The Agricultural Code of Practice (1976) provides manure management guidelines to reduce the impact of livestock wastes on water quality. The Code of Practice specifies requirements for manure storage, prohibits winter spreading, recommends manure incorporation and establishes minimum land areas for livestock operations based on the nitrogen in the manure. The basic recommended annual rate of manure application to land is 2.5 'animal units' per hectare. The rate is based upon nitrogen required for continuous corn production. The Code suggests that manure disposal at up to twice this rate is allowable without environmental detriment on soils of loam texture or finer. The maximum rate for sandy soils is 3.3 animal units per hectare. Miller et al. (1989) do not feel that this recommendation has been adequately tested in Ontario. They recommend that the maximum acceptable rate of nitrogen application should be based on the contribution of nitrate to ground water, not on the requirement of the crop.

To optimize crop utilization of manure nitrogen, manure should be applied just before planting and incorporated directly. Beauchamp (1983) has reported possible manure application periods for different crops. Liquid manure may be preplant applied to corn in April/May, side dressed in June or applied post harvest from September to November.

Beauchamp and Kachanoski (1990) have reported on the compatibility of conservation tillage and manure spreading. They suggest that conservation tillage practices should work well with manure injection systems by conserving nitrogen and reducing nutrient runoff losses. Chisel plowing after manure application probably results in sufficient crop residues left on the soil surface to prevent significant runoff of nutrients. Incorporation of manure into no-till cropping systems remains a problem. The authors cite a Quebec study that found when manure was used as a source of nitrogen in a no-till corn crop, poorer corn seedling emergence, weed control and an increased risk of frost damage occurred.

Fleming et. al.(1982) reported that the traditional way to spread liquid manure is with a liquid manure tanker. Tankers vary in size from about 4000 L to 18,000 L. Recently, irrigation of liquid manure has become popular because of reduced time and labour costs and lower risks of soil compaction compared with tanker applications. Liquid manure injection systems have been used successfully in preplant and side dress applications in corn cropping systems (Beauchamp 1983). Injection systems are now being modified for use in no-till or forage systems.

A significant impact of excessive application of manure is an increased concentration of nitrogen in tile drainage or ground water. In Ontario a few published studies are reporting the impact of manure on subsurface water quality. However, ground water studies close to manure storage facilities have been conducted by Gillham and Webber (1969) and Miller et al. (1976). Gillham and Webber (1969) found nitrate concentrations of 15 mg/L close to the manure storage and concentrations of 5 mg/L at distances of 90m from the manure source. Miller et al. (1976) reported high ammonium concentrations to four metre depths under older hog manure lagoons on medium and coarse textured soils.

Miller et al. (1985) studied ground water in a southern Ontario field with a history of over application of manure. Over a 3-year monitoring period, the nitrate-N concentrations were consistently above 30 mg/L. On a sandy soil in eastern Ontario, Patni et al. (1981) showed that five years of manure application at an average rate of 840 kg N/ha/y on corn cropland resulted in nitrate concentrations of 30-40 mg/L and ammonium concentrations of 9-29 mg/L to 6m depths. Phillips et al. (1981) found that spring nitrate levels in tile water reflected manure application rates. In a subsequent study Phillips et al. (1982) reported tile effluent concentrations of 19 mg/L for corn with 570 kg manure N/ha/y applied. Nitrate concentrations in tile drainage were highest in the early spring. Beak Consultants (1977) found that 97% of the nitrogen in the tile drain discharge was nitrate while 3% was organic nitrogen in a southwestern Ontario watershed.

Tile drain nitrate concentrations do not often correlate with ground water nitrate levels. Starr and Gillham (1987) have shown that ground water nitrate levels can be reduced in the presence of organic carbon through denitrification. In eastern Ontario heavily manured fields were found to have nitrate concentrations of about 10 mg/L in shallow ground water, while ground water at 6m depths had nitrate concentrations of less than 1 mg/L.

It is frequently assumed that bacteria are not transported great distances through the soil matrix, however recent studies have suggested that bacterial transport through soil macropores may be a significant process in contamination of tile drainage waters. Patni et al. (1984) reported the increase of fecal bacteria population in tile drain water minutes to hours after irrigation with liquid manure. In tile drains with an average depth of 75 cm, Culley and Phillips (1982) observed high fecal bacteria counts for several days following fall or winter application of liquid manure. Recent studies by Dean and Foran (1991) in southwestern Ontario have further increased concern with respect to direct transport of bacteria to tile drains from liquid manure applications. In field studies, tile drains became contaminated with fecal coliform shortly after liquid manure applications for nine of 12 events monitored. Tillage of the soils prior to manure application appears to disrupt macropore continuity and prevent bacteria transport to the tile drains. The role of macropores in the transport of surface applied nutrients is not yet well understood. This problem is a particular concern for no-till fields where agricultural amendments must usually be applied to the soil surface and macropore systems are not subjected to periodic disruption by tillage (Shipitalo et al. 1990).

Field scale water quantity and quality models have proven useful for the management of agricultural resources. They have been used extensively to evaluate the impact of a wide range of land management scenarios on water quality. DRAINMOD is the most widely used drainage model in North America (Skaggs 1978). Singh et al. (1992) have improved DRAINMOD for use in Ontario by incorporating snowmelt and nutrient transport components. The model has been developed to simulate nutrient transport under water table conditions induced by tile drainage but needs to be validated for Ontario conditions before it can be used for farm level conservation planning.

Objectives:

In a joint effort between Agriculture and Agri-Food Canada, the Upper Thames River Conservation Authority and the Ontario Ministry of Agriculture Food and Rural Affairs, this study was conducted with the following objectives:

1) Conduct field scale studies of liquid manure application technologies for different soil/climatic conditions;
2) Evaluate application technologies in no-till corn cropping systems in terms of sustainable crop productivity and subsurface water quality (nitrogen, bacteria);
3) Identify pathways and processes of nutrient and bacteria transport to tile drains and ground water with special consideration to preferential flow;
4) Validate tile drainage water quality model (DRAINMOD) with field scale data and use models to identify scenarios in which water quality standards are likely exceeded.
5) Develop liquid manure application recommendations for environmentally sustainable no-till corn crop production.

3.0 METHODOLOGY

3.1) Site Properties

Three (2 ha) field sites were selected for study with contrasting soil textures (medium-silt loam, light-sandy loam and heavy-silty clay loam), systematic tile drainage (minimum of 12 tiles) and a no-till corn crop management system. These sites were located in the Mixedwood Plains ecozone, Manitoulin-Lake Simcoe ecoregion (Ecological Stratification Working Group, 1995).

A 120m x 90m field at each site was divided into 12 plots which were further randomly divided into four treatments (replicated 3 times).

The medium textured site (Site 1) was located in the Kintore watershed (Lat. 43º10'05", Long. 81º03'00"; UTM - N 4779200, E 495900) in Zorra Township, Oxford County on an Embro silt loam soil series (Gleyed Gray Brown Luvisol) with gentle sloping topography (~ 4%). The field was in a corn-soybean-alfalfa rotation, and had been in no-till for eight years prior to the experiment. Three years of alfalfa followed by one year of corn was the cropping sequence immediately prior to the experiment. The site was originally systematically tile-drained in 1940, and with plastic 10 cm diameter tiles at an average depth of 0.87m (0.79-1.07 m) and spacing of 6.8m (6.4-7.9 m).

The light textured site (Site 2) was also located in Zorra Township (Lat. 43º01'30", Long. 80º58'45"; UTM - N 4763450, E 501680), Oxford County. The soil series was a Brisbane sandy loam (Gleyed Gray Brown Luvisol) on gentle sloping topography (~ 4%). The field was in a corn-soybean-alfalfa rotation. Three years of alfalfa followed by one year of corn was the cropping sequence immediately prior to the experiment. The site was systematically tile-drained in 1984 with 10 cm plastic tiles at an average depth of 0.80m (0.73-0.87m) and average spacing of 10.0m (9.4-10.3m).

The heavy textured site (Site 3) was located in Adelaide Township, Middlesex County (Lat. 42º57'40", Long. 81º43'40"; UTM - N 4756600, E 440650). The soil series at the experimental site was a Perth silty clay loam (Gleyed Brunisolic Gray Brown Luvisol) on gentle sloping topography (~ 3%). The field was in a corn-soybean-winter wheat rotation and had been in no-till winter wheat for one year prior to the experiment. The field was systematically tile-drained in 1971 with 10cm clay tiles at an average depth of 0.68m (0.62 to 0.83m) and spacing of 14.5m (13.7 to 15.2m).

Several detailed soil pits were completed to determine the general soil physical and chemical properties for the three research sites. The surficial soils have clay contents ranging from 13.0% on average at Site 2 to 33.5% at Site 3. Organic matter levels range from 3.1% at Site 3 to 4.9% on average at Site 1. Soil series and drainage classification were assigned to each location. Soil penetrometer resistance and soil moisture for each plot were conducted on the day of the experiment using an automated soil cone penetrometer and grab samples (gravimetric soil moisture). Detailed soil characteristics for each site are given in Appendix A.

3.2) Field Methods

I) Water Quality/Quantity

At each field site, about 100 m of 12 tile drains were intercepted at depth and 22 L pails were inserted into the tile lines. Flow was monitored by water bilge pumps (Attwood V1250, pumping capacity at zero head was 4087 L/hr) placed in each pail that pumped incoming flow from the tile back to the out flowing tile (Fig. 1). A Campbell Scientific CR10 electronic data logger recorded the real time and the duration and number of times the pump ran in each 30 minute interval. The volume of water each pump delivered during a pumping cycle varied between pumps, therefore every pump was calibrated with manual flow rates taken weekly throughout the growing season (May to October), and at 15 minute intervals during the two days of the experiment each year.

Water quality samples were taken weekly throughout the growing season while tiles were flowing. On the 2-3 days of detailed experimentation each year, samples were taken at 15 minute intervals from the start of manure application or simulated rainfall event and continued for three hours. Following the 3-hour period, automated water quality samplers were used to take samples at 3 hour intervals for the next 24 hours. Samples taken for nitrate, ammonium and soluble phosphorus were filtered through 0.45-µm filter paper on the site or immediately upon reaching the laboratory. Bacteria samples were placed in a cooler until they were delivered to the laboratory.

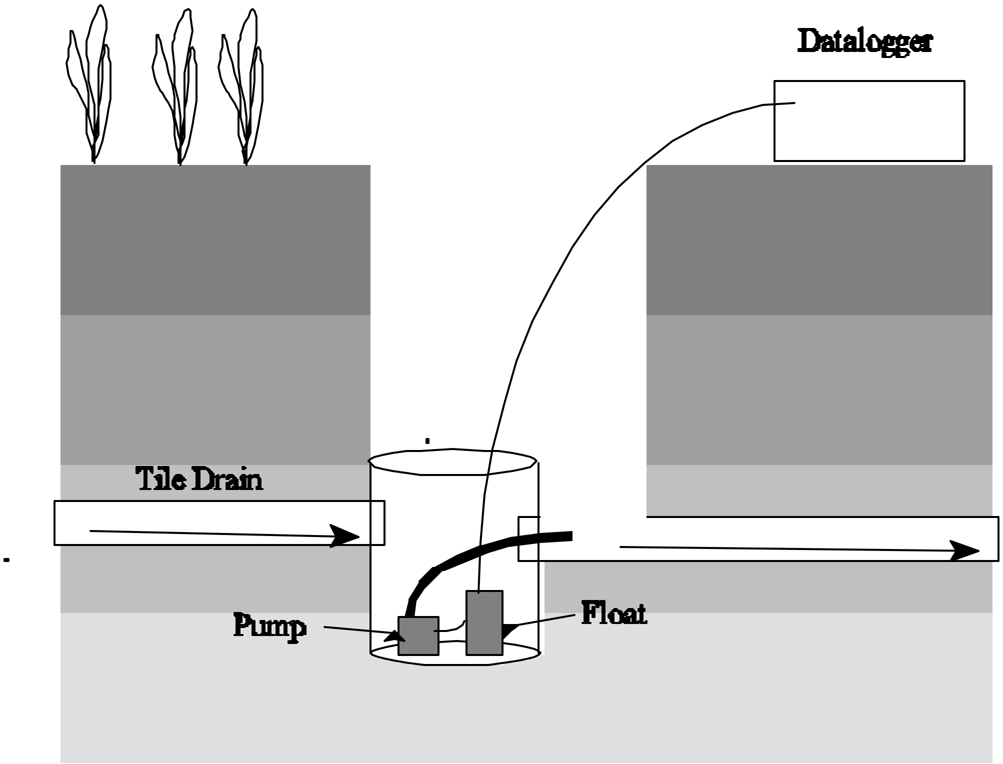

Fig. 1. Schematic drawing of the tile flow monitoring equipment

II) Climatic Monitoring

An automated meterological station was setup at each experimental site and instrumented to measure hourly temperature and relative humidity, 15 minute precipitation, daily wind speed and wind direction. The sensor information was recorded using a Campbell Scientific CR10 data logger (Campbell Scientific Inc., 1992).

III) Agronomic Monitoring

A no-till corn crop was planted at each field site using commercial no-till planters outfitted with various coulter and trash whipper arrangements to manage the corn residue. Starter fertilizer was applied with the planting units (ranging from 5-36kg N/ha, 6-14kg P/ha, 0-26kg K/ha)(Appendix E) as to the cooperators preference with the highest rates applied at Site 3. Sites 1, 2 and 3 were planted May 31, 1994 and June 1, 1995; May 16, 1995 and May 27, 1996 and May 30, 1996 respectively. The area being drained by each of the 12 tiles (about 100 m by 7 m) were treated as individual plots to monitor crop and water quality response to liquid manure application. The three tiles treated as control plots were fertilized at the time of planting according to soil test recommendations (ranging from 57-161kg N/ha, 0-32kg P/ha, 0-55kg K/ha)(Appendix E). Herbicide applications were typically a preplant burndown using glyphosate and possibly a residual grass control herbicide followed by a post emergent 2,4-D or atrazine application, all at recommended rates(Appendix E).

Manure was applied down the centre of each plot in a 7m wide strip directly over the tile. A 6800L (1500 Imp. gal.) commercial manure tanker outfitted with a dual toolbar at the rear with four injector teeth mounted at the back for subsurface application, was used to apply the manure, using three application techniques described by Hilborn et. al.(1994), McLaughlin et. al. 1997:

1) Surface applied (The injectors were lifted off the ground and the manure was applied to the soil surface). Manure is spread over the entire width between the corn rows (76 cm).
2) Conventional injection(5 cm shovels injecting at 10 cm depths below the soil surface). Manure is concentrated in a narrow band approximately 5 cm wide down the centre of each row.
3) Modified injection (fluted coulters and 5 cm wide cultivator teeth mounted on a toolbar in front of the injectors, to provide minor cultivation (13 cm depth) prior to manure injection). Manure is concentrated in a band approximately 15 cm wide down the centre of the row.

Nutrient analysis of soil and manure samples taken about seven days before application and tested at the University of Guelph, Dept. of Land Resource Sciences, Analytical Services laboratory, was used to compute the rate of manure needed to supply the nitrogen requirement for the crop (150 kg/ha)using OMAFRA pub. 296. Liquid manure analysis (N,P,K), for each site are given in Appendix E. A bacteria tracer (Escherichia coli/Natidixic acid resistant)(Rhae, T.M. et al. 1979) and chemical tracers (strontium chloride 1994 at Site 1 at 2.4g/L and potassium bromide 14.7 mg/L for Site 1 in 1995 and sites 2 and 3 in 1996) were added to the liquid manure immediately prior to land application. Bacterial analysis of manure samples taken several days prior to application were used to determine the concentrations of bacteria tracer required to act as an effective biological tracer.

Liquid hog manure was side-dressed to the manure treatment plots around the fourth leaf stage on the following dates: Site 1- June 28, 1994 (69,650 L/ha) and June 27, 1995 (62,900 L/ha); Site 2 - June 13, 1995 (71,900 L/ha) and June 26, 1996 (69,650 L/ha); Site 3 - July 3, 1996 (56,200 L/ha).

A rainfall event was simulated the day following manure application by using a travelling gun irrigation system to apply about 2.5cm (257,000 L/ha) of water onto the field plots over a

3 hour period (20 to 30 min/plot). Water samples were taken periodically during the simulated rainfall event and analysed for nutrient concentrations and bacteria counts.

Scouting of crop performance from time of emergence to harvest recorded any differences between treatments. Plant population counts were carried out at emergence, during the experiment period, and at harvest. The time of plant silking was estimated for each treatment to determine any delays in maturity. Leaf tissue analysis was done at this time to check for nitrogen and other nutrient deficiencies. Weed scouting identified problem areas and potential crop competition. Surface crop residue cover was measured prior to manure application. Yield monitoring was the critical crop performance indicator. At harvest, population, plant lodging, grain moisture and yield were measured for each plot. Plot grain weight was determined by a weigh wagon and a representative grain sample was analyzed with a moisture meter. Harvest was in late October or November except at Site 3 where wet fall conditions prevented access until field freeze-up in January. Lodging of more than 50% across the Site 3 field reduced yields. All corn yields were adjusted to 15.5% moisture.

To determine the cost effectiveness of modified injection, a comparison of draft and fuel consumption between the methods of manure application was carried out using Agriculture and Agri-Food Canada’s instrumented tractor (McLaughlin et al. 1993). The tractor is fitted with a set of transducers and an onboard data logger to measure and record the tractor operating parameters, including speed, draft and fuel consumption. Six replications were conducted for each application method and six replications for the tractor by itself to obtain baseline data. Tests were conducted using the methodology described by McLaughlin et al. 1997.

3.3) Micro Plot Monitoring

Three replicate 1m x 1m plots were established at Site 1 directly over lysimeter pans which were approximately 50 cm below the soil surface, and had been installed 12 months earlier. All live plant material was cut off at the soil surface. Each plot was instrumented with 18 vertical TDR (Time Domain Reflectometry) probes at three depths (10, 20 and 30 cm(6 probes/depth)). Three additional probes, one per depth, and thermocouple temperature sensors were installed outside the plot (Fig. 2) to determine any variations in temperature and moisture that could effect the readings. The plots were bounded by galvanized metal borders to prevent the movement of water and/or tracer off the plot. The plots were covered with plywood to prevent the additional input of water from rainfall and to reduce evaporative losses. The plywood was removed only during water and tracer application.

Each day at approximately the same time, the TDR was used to measure water content and soil impedance (ohms) prior to water application. Following the readings, 24 L of water was applied slowly to ensure no surface runoff using a watering can. This daily application of water continued until the readings from the TDR indicated that the soil had reached steady-state moisture content. The chemical tracer was then added with the following day's water. A total of 150 grams of strontium chloride in solution was applied to each plot. Following the day of tracer application, 24 L of water was applied again on a daily basis until the TDR impedance (ohms) readings returned to baseline readings, or leveled off.

Water from the lysimeter pan was sampled every 3 hours following tracer application for the first day and then every 6 hours for the following days. Sampling was then conducted once a day for the remainder of the experiment. After the last TDR reading had been taken, soil samples were taken from each plot. All soil and water samples were analyzed for strontium chloride concentration..

3.4) Laboratory Methods

Soil and nutrient analyses were done at the Department of Land Resource Science, Analytical Services laboratory, University of Guelph. Bulk density (Uhland core sampler), particle-size distribution (pipette analysis with organic matter destruction and Calgon^{TM} dispersion), pH (calcium chloride) and organic matter content (wet combustion) were measured using standard methods (McKeague 1978). Nitrogen, phosphorus and potassium were analyzed in the soil and manure samples. Total phosphorus and total nitrogen concentrations in tile water samples were measured following digestion (Thomas et al. 1967). Ammonium N (NH_4^+), nitrate N (NO_3^-) and soluble phosphorus were determined from field-filtered samples (Clesceri et al. 1989). Plant tissue analysis was conducted on prepared sample leaf material (Jones and Case 1990).

Bacteriological analysis (total coli, fecal coli, labeled E.coli) was conducted on tile water and manure samples by the Ontario Ministry of Environment and Energy, London, Ontario using standard methods. A minimum amount of 150 ml of water was required to conduct the bacteria analysis (maximum of 250 ml). Strontium and chloride analyses were conducted by the University of Guelph, Analytical Services laboratory.

Statistical analyses of treatments (means, standard deviations, and analysis of variance) were conducted using Statsgraphics Plus software (Statistical Graphics Corp. 1995). A probability level of 90-95% was considered the lowest level at which statistical significance occurred.

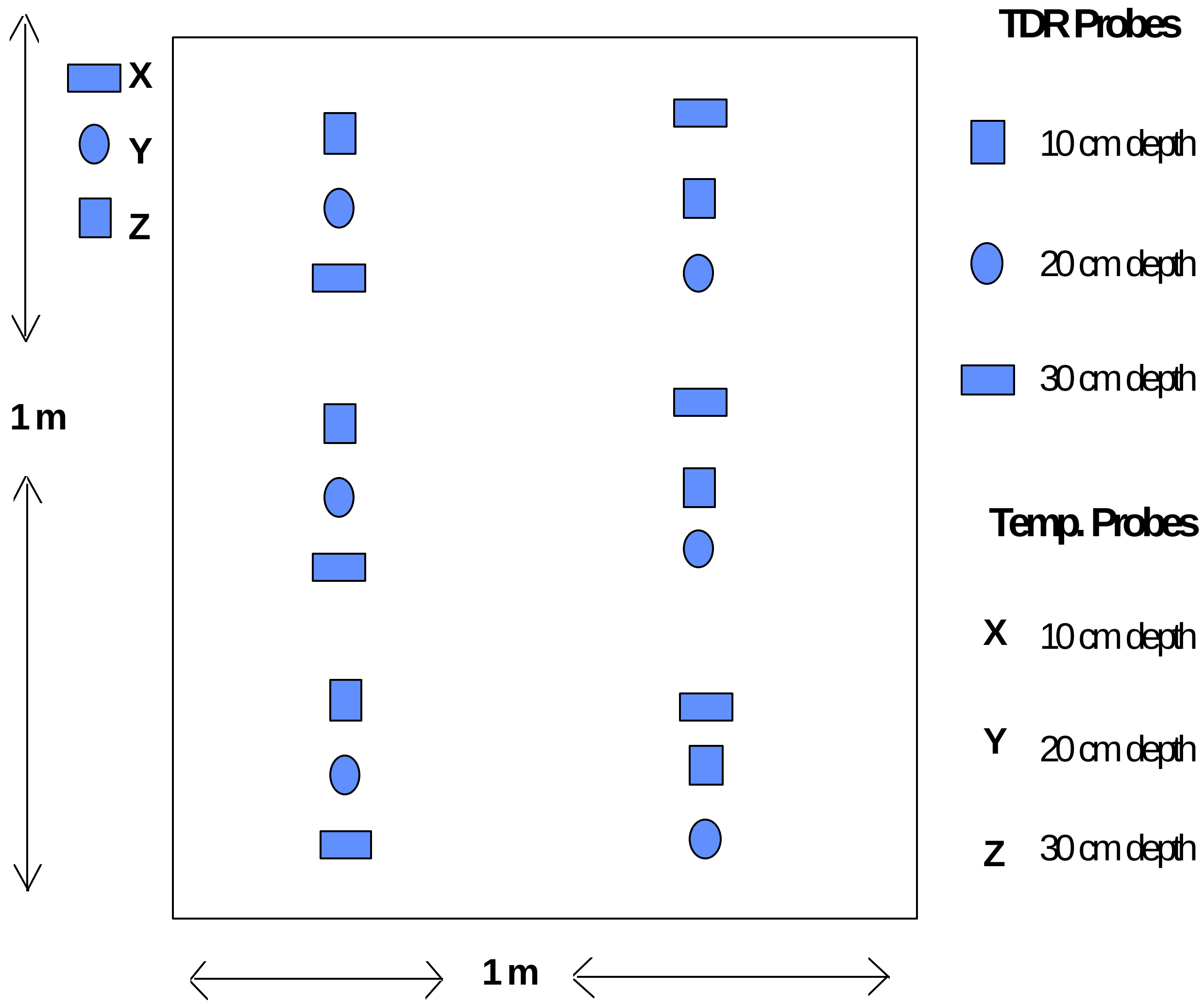

Fig. 2. Location of TDR probes and thermocouple sensors in the micro plots at Site 1.

3.5) Modelling of Tile Flow

DRAINMOD version 4.0 (Skaggs,et.al., 1990) was used to model tile drain flow at Sites 1 and 2. Temperature and rainfall input files were created with the available daily and hourly meteorological data (COSEA Rep. # RES/MON-009/97 - Agriculture and Agri-food Canada, 1997). Soil data input files were also created using data collected at three representative soil characterization sites (Pits 1 to 3 - Appendix B). For Site 1, pit 1 data was used for tiles 1 and 2, pit 2 data was used for tiles 3 - 6 and pit 3 data was used for tiles 7 - 12. The soil data from 3 soil characterization sites at Site 2 were averaged and used for all the tiles due to inconsistencies in the hydraulic conductivities. Potential evapotranspiration (PET), and hydraulic properties such as Green and Ampt infiltration parameters and upward flux were not available, so the model calculated them internally.

The following data was manually entered into the program. The spacing between tile drains at Sites 1 and 2 were 6.8 m and 9.76m respectively, which was an average of the distances between all twelve tiles. The drain depths were actual measured depths for each tile (Appendix B). The drainage coefficient was calculated to be 2.8 cm/day, assuming that the area drained by the tile is its length multiplied by half the distance between it and the tiles on either side of it. Neither site had a measured impermeable layer, so the depth to the impermeable layer was assumed to be greater than 10m. It was assumed that there was no down slope seepage, vertical seepage or lateral seepage and the slope down the field remained constant for both of the sites. All trafficability and general crop inputs of wet stress and drought stress were estimated and are equivalent for both of the sites (Appendix B). The root depths through the season were estimated using the relationship of 60% of total root length existing versus time after planting for corn, suggested to be successful in the model by the Drainmod User's manual. In fallow periods, a value of 3 cm was used to reflect the soil depth from which water would evaporate without a crop. No actual measurements of lateral saturated hydraulic conductivity were taken, therefore an initial estimate of the measured vertical hydraulic conductivities for each horizon was used.

The effective radius of the drain at both sites was the given value of 0.51 cm from the Drainmod User's manual for a 10cm corrugated pipe. The surface storage value and Kirkham's depth of flow to drain for Site 1 were given values of 2.0 cm and 1.5 cm respectively, for its specific site conditions of poor drainage. For Site 2, these values were also given as 0.5 cm and 0.4 cm for its specific site conditions of good drainage. The initial water table depth used was half the tile drain depth, suggested by the Drainmod manual, since it was not measured. The model was then run continuously (January to December) for two years (94-95 for Site 1, 95-96 for Site 2) to create background soil conditions.

An initial run of the program with the Site 1 data did not produce any output. The most sensitive input parameters were evaluated and modified in order for the program to run. Thooko (1990) determined that Drainmod predictions of tile outflow were most sensitive to PET estimate, lateral saturated hydraulic conductivity, upward flux, drained volume, soil moisture at wilting point, depth to the impermeable layer and crop rooting depths. PET estimate, upward flux and drained volume were variables calculated by the model, therefore were not changed. Testing of the remaining parameters indicated variable sensitivity. Soil moisture at wilting point and crop rooting depths proved to be insensitive, therefore depth of the impermeable layer and lateral hydraulic conductivities were the only two parameters changed.

The impermeable layer for Site 1 was modified by decreasing the depth until runoff was created for the simulated rainfall event in 1994 when runoff was observed to occur. The initial lateral hydraulic conductivity was assumed to be the same as the measured vertical hydraulic conductivity that produced largely overestimated flows. The minimum allowable lateral hydraulic conductivities used were 0.2 cm/hr, 0.01 cm/hr and 0.1 cm/hr for each consecutive horizon. The model was run again and results for the growing season (May to September) were compared with the actual data for validity using a 95% least significant difference (LSD) test.

An initial run of the program with the Site 2 data produced unrealistic output for drainage and surface runoff. It was assumed that Site 2, which had a coarse textured soil, would have minimal surface runoff. The impermeable layer for Site 2 was modified to achieve a depth that would create no surface runoff but would allow the program to run. The lateral hydraulic conductivities were modified for realistic tile flow and no surface runoff. The resulting values chosen were a quarter of the vertical hydraulic conductivity. They were 2.21 cm/hr, 0.92 cm/hr, 1.05 cm/hr and 0.42 cm/hr for each consecutive horizon. The model was run again and results for the growing season (May to September) were compared with the actual data for validity using a 95% least significant difference test.

4.0) STUDY RESULTS

4.1) Study Site 1

4.11) Site Properties

The Embro soil series, the dominant soil at site 1, is the imperfectly drained soil of the Honeywood association. It consists of a silt loam textured surface overlaying a calcareous silt loam to silty clay loam till. The site has a high (4.9%) organic matter level in the plow layer. Detailed soil information is given in Appendix A. Soil moisture was quite high on the day of manure application in both 1994 and 1995 due to heavy rainfall prior to the experiment. The gravimetric soil moisture across the field in 1994 ranged from a low of 25% to a high of 32% with an average moisture content of 29%. In 1995 the soil was drier with a low moisture content of 22% and a high of 31%. The average soil moisture content was 26%.

Penetrometer resistance was measured just prior to the time of manure application. The average value for the field at a depth of 10 cm was 663 kPa in 1994 and 869 kPa in 1995. A measurement at the 30cm depth was also conducted in 1995, and the average value for the field was 1356 kPa. There was no significant difference between the tiles at an LSD level of 95% in both years.

4.12) Tile Flow

I) Seasonal

Tile flow for the May to October growing season of 1994-95 is reported in Appendix C. The tiles flowed throughout the growing season, except for a 35 to 45 day period in mid August to early October in both years. There was a relatively quick response of the tiles to a rainfall event from May until mid July. As the soil became drier tile flow response slowed to a point where even a 25mm rainfall event did not create tile flow. Peak monthly flow rates of 3.67 L/min in 1994 and 11.65 L/min in 1995 were observed in May that declined to flows of about 0.47 L/min in 1994 and 1.16 L/min in 1995 in the beginning of August. Once flows were initiated again in October in 1995, flow rates increased to about 3.12 L/min by mid October. Flow rates only increased slightly in 1994 (0.02 L/min) by early October. No data was collected beyond the first few days in October in 1994.

II) Liquid Manure Application Day

The tile drains were flowing on the day of liquid manure application in both study years. In 1994 tile flow rates ranged from a high of 2.30 L/min to a low of 0.28 L/min. The average flow rate was 1.68 L/min with a standard deviation of 0.58 L/min. In 1995, the tile flow was lower for all tiles with flows ranging from a high of 1.34 L/min to a low of 0.260 L/min. The average tile flow rate was 0.98 L/min with a standard deviation of 0.29. Statistical analysis was conducted on tile flow to determine if there was a significant difference between tile treatments and years. Since no significant difference in tile flow rates was found, all tiles were treated equally. Background tile flows and treatments are given in Table 1.

Table 1. Tile flow rates and treatments prior to liquid manure application, Site 1

Tile Number	1994		1995	
	Treatment[1]	Flow Rate (L/min)	Treatment[1]	Flow Rate (L/min)
1	MI	2.30	CI	1.00
2	CI	1.60	MI	0.84
3	SA	1.29	CO	0.93
4	CO	1.92	CI	1.12
5	MI	2.28	SA	1.24
6	CO	1.74	MI	0.92
7	SA	1.73	CO	1.04
8	CI	1.63	SA	1.34
9	MI	2.13	MI	1.16
10	CO	2.28	SA	1.26
11	SA	0.99	CI	0.60
12	CI	0.28	CO	0.260

[1](MI - modified injection, CI - Conventional injection, SA - Surface applied, CO - Control)

Liquid manure applied to the plots at rates of 69,645 L/ha in 1994 and 69,905 L/ha in 1995 resulted in increased flows to all tiles for several hours following application, with tiles returning to baseline levels within three to four hours. Peak flows were observed within the first 30 minutes for all treatments for both years. The hydrographs for the three-hour period following manure application are shown in Figure 3.

In 1994 flow rates increased an average of 0.60 L/min. The greatest increase in flow rates occurred under the surface applied treatment (1.40 L/min) and the smallest increase (0.30 L/min) occurred under the conventional injection method. The modified injection method had an average flow rate increase of 0.50 L/min. There was no flow increase under the control tiles. Flow rate increases were the opposite in 1995. The surface applied flow rate only increased by 0.10 L/min while the modified injection increased by 0.35 L/min and the conventional injection increased by 0.23 L/min. The average flow rate increase was 0.22 L/min. Again there was no increase in flow under the control tiles. Due to high variability in tile flow, the increases were not significantly different at an LSD of 90% in both years. In 1994, an average of 1.8% of the applied volume of liquid manure came through the tiles, with the highest amount, 2.5% from the surface applied. The percentage of applied reaching the tile drains was lower for both injection methods with values of 1.4% for the modified injection and 1.6% for the conventional injection. In 1995 the values were much lower with the average volume of manure entering the tile drains being 0.7% of applied. The greatest amount of applied manure reaching the tile drains was from the injection methods (1.0 % for modified injection and 0.8% for conventional injection) and the lowest amount from the surface applied method (0.3%). There was no significant difference between the treatments in either year at the 90% confidence interval.

III) Simulated Rainfall Event

No simulated rainfall was applied in 1994 due to heavy rainfall the day following manure application. On the day of the simulated rainfall event in 1995, a total of 3.2 cm of water was applied over approximately a 3 hour time period to the field using a travelling irrigation gun (approximately 20 min/tile). All tile flow rates increased dramatically. Flow rates increased by an average of 22 L/min for surface applied, 23 L/min for modified injection, 18 L/min for conventional injection and 24 L/min for the control tiles. All flow rates peaked within 90 minutes following the start of the simulated rainfall event, and did not return to baseline levels for several days. Flow rates for the three hour period following the simulated rainfall event are shown in Figure 4. The volume of water reaching the tile drains averaged 9.6% of applied for all treatments (control - 10.7%, modified injection - 10.3%, conventional injection - 8.1% and surface applied - 9.4%). Total flow volumes in the three hour period following the simulated rainfall event were not significantly different at an LSD confidence level of 90%..

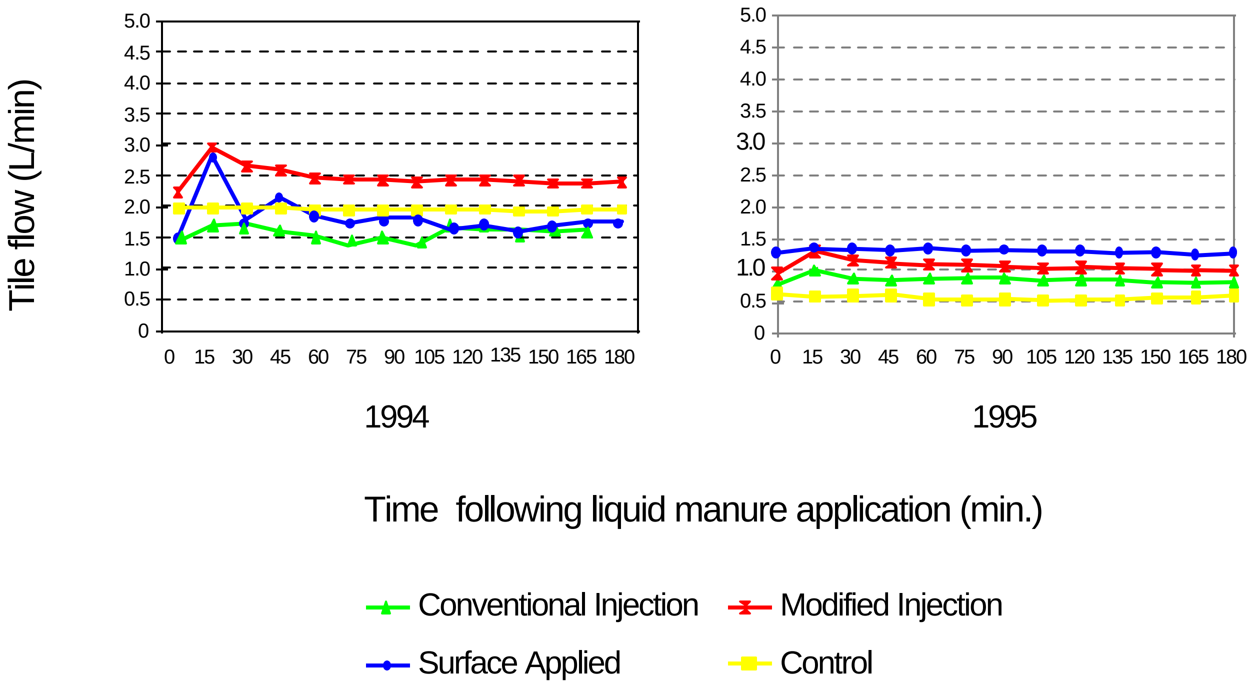

Fig. 3. Tile flow following liquid manure application (1994/1995) for Site 1.

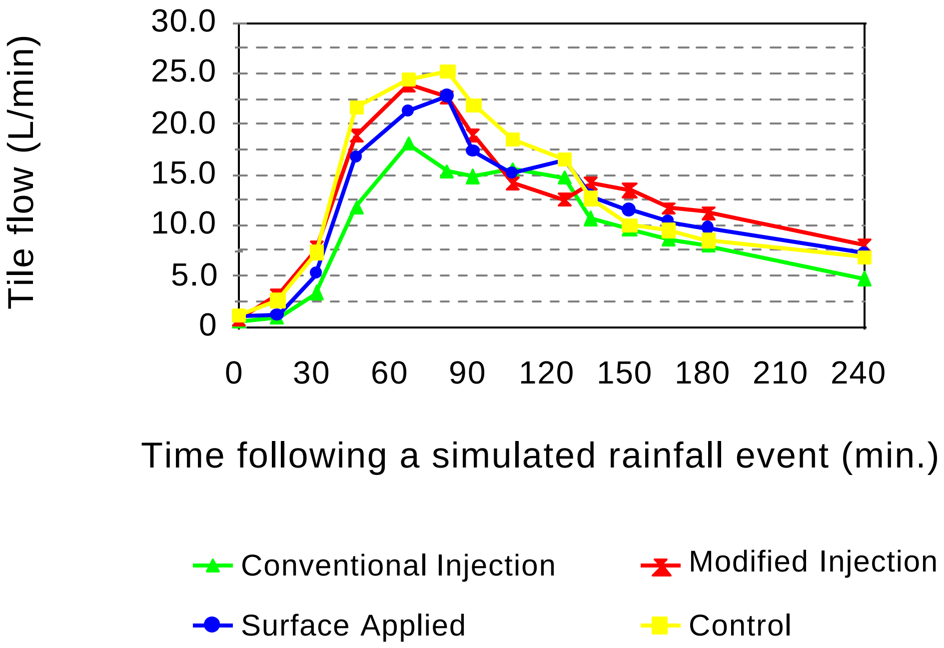

Fig. 4. Tile flow following a simulated rainfall event (1995) for Site 1.

4.13) Water Quality

I) Seasonal

Nitrate concentrations were usually <8 mg/L during the growing season in both years (Appendix D). The tile nitrate concentrations were not immediately affected by the application of manure during the first few days following manure application; however, there was an increase in concentrations about one week later (up to 30 mg/L - 1994 and 15 mg/L - 1995) from all treatments. Nitrate concentrations returned to background levels within 2 weeks following application. A few total phosphorus samples were collected during the growing season and the values usually exceeded the water quality guidelines (<0.03mg/L). Soluble phosphorus was steady throughout the growing season ranging from a low of 0.05 mg/L to a high of 0.15 mg/L. There was no difference between treatments prior to, and following manure application.

II) Liquid Manure Application

Concentrations of ammonium, phosphorus and bacteria increased within the first three hours following manure application (available from COESA Report No.:RES/MON-009/97 - Agriculture and Agri-Food Canada, 1997). Manure contamination of the tile water was visually evident within as little as seven minutes following manure application under the surface applied method in 1994 and 10 minutes in 1995. It took an average of 20 minutes for the manure to become visible in the tile drains under conventional injection and modified injection in both years. The chemical tracers were also detected in the tile water within the first three hours following manure application.

Ammonium concentrations increased sharply within 30 minutes following manure application under all application methods in both years. In 1994 concentrations of ammonium increased above aquatic water quality standards (1.37- 2.2 mg/L) from 0 to 275 mg/L, 92 mg/L and 175 mg/L for the surface applied, modified injection and the conventional injection respectively. The concentrations of ammonium in the control tiles did not change. In 1995 the modified injection method had the greatest increase in ammonium concentrations with values peaking at 180 mg/L. Conventional injection and the surface applied treatments also increased, but by smaller amounts (Fig. 5).

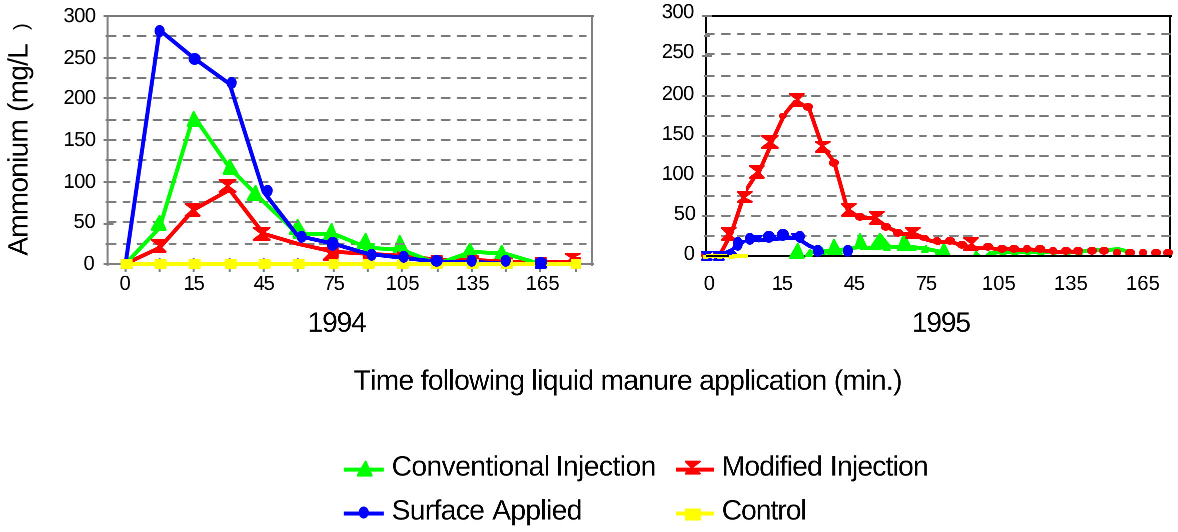

Fig. 5. Ammonium concentrations in the tile water following liquid manure application (1994/1995) for Site 1.

Ammonium loadings in the tile drains were calculated for a three hour period following manure application for both years. Total loadings of ammonium were greatest for the surface applied (38.54 kg), followed by conventional injection (10.06 kg) and modified injection (9.48 kg) in 1994. Both injection methods decreased ammonium loadings compared with the surface applied by 72% and 75%, for the conventional injection and the modified injection respectively, but there was no statistically significant difference ($p>0.1$) between injection treatments due to high variability. In 1995 the ammonium loadings were less, with values ranging from a high of 10.548 kg for modified injection to a low of 0.78 kg for the conventional injection. The surface applied method was in between with 0.89 kg of ammonium reaching the tile drains. Modified injection was significantly greater than the surface applied and the conventional injection treatments. All treatments were significantly greater than the controls.

In 1994 and 1995 bacteria tracer (E. coli) levels in the tile drains exceeded drinking water quality standards (0 counts/100ml) within 15 minutes following application for all treatments. Bacteria tracer levels increased from 0 counts/100ml for all treatments to $1.25x10^6$ counts/100ml for conventional injection, $2.5x10^6$ counts/100ml for modified injection and $5.0x10^6$ counts/100ml for surface applied. Values peaked within the first hour for surface applied and modified injection but not until the two-hour mark for conventional injection. A small amount of bacteria was found in the control tiles, which may be attributed to cross contamination or laboratory error. In 1995 the bacteria concentrations were much smaller. The values ranged from $1.68x10^5$ counts/100ml to $1.88x10^5$ counts/100ml for the surface applied and modified injection respectively (Fig. 6). Due to the interval sampling, the peak value for conventional injection may have been missed, but the greatest recorded value was $1.2x10^5$ counts/100ml.

Bacteria loadings in the tile drains were calculated for 1994 (3-hour period)and 1995 (45 minute period). In both years bacteria loadings for the surface applied was significantly greater than the control tiles. There was no significant difference between manure treatments, although bacteria loadings from the surface applied was much greater than either injection method (Fig. 7).

Manure application resulted in greater total phosphorus concentrations in the tile drains under all application methods in both years, with all treatments exceeding water quality guidelines (0.03 mg/L)(Fig. 8). Values peaked as high as 55 mg/L under surface applied in 1994 and 56 mg/L in 1995 under modified injection. The greater soil moisture in 1994 seemed to have an effect on the amount of phosphorus reaching the tile drains. Some of the phosphorus in the drier year (1995) may have come from soil which had been loosened with the modified injection pre-tillage and transported to the tile drains with the liquid manure (water samples taken in 1995 were muddier than water samples taken in 1994). There is no way of determining how much phosphorus came from the manure and how much may have been extracted from the soil by the manure, due to the small percentage of phosphorus reaching the tile drains in comparison to the amount in the liquid manure. Soluble phosphorus values also increased under all manure treatments with modified injection having the highest increase in 1994 (7.2 mg/L) and in 1995 (18.7 mg/L). There was no significant difference between treatments and years. Total soluble phosphorus loadings for a three hour period following manure application in 1994 and 1995 are shown in Figure 9.

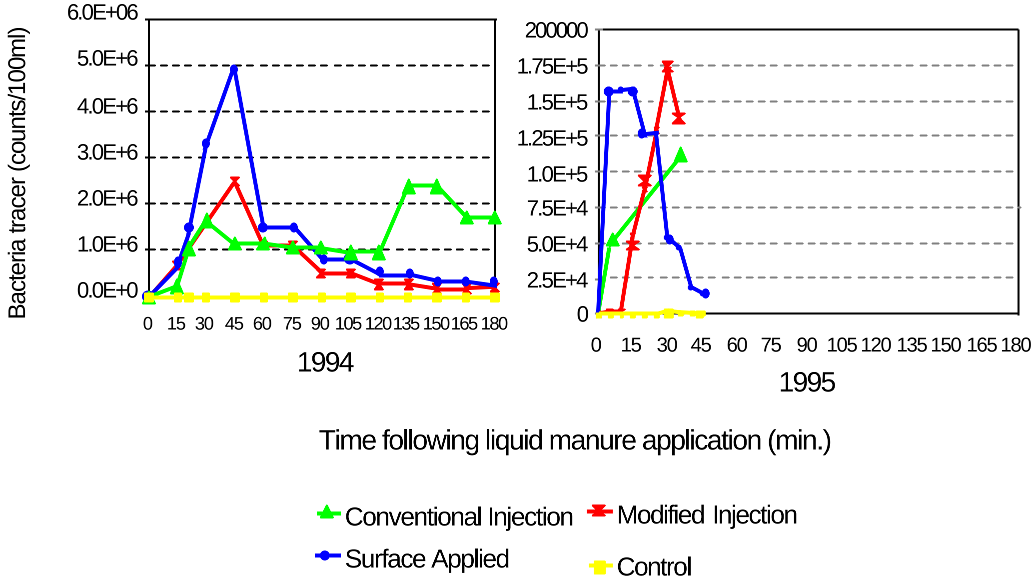

Fig. 6. Bacteria tracer concentrations in the tile water following liquid manure application (1994/1995) for Site 1.

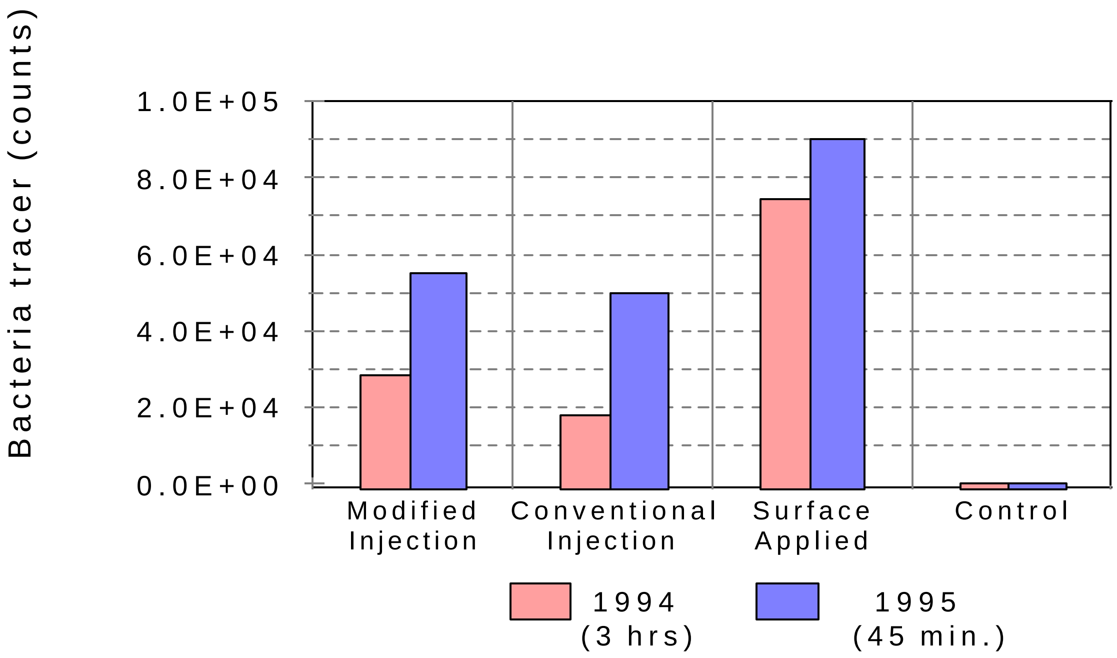

Fig. 7. Bacteria tracer loadings in the tile water following liquid manure application (1994/1995) for Site 1.

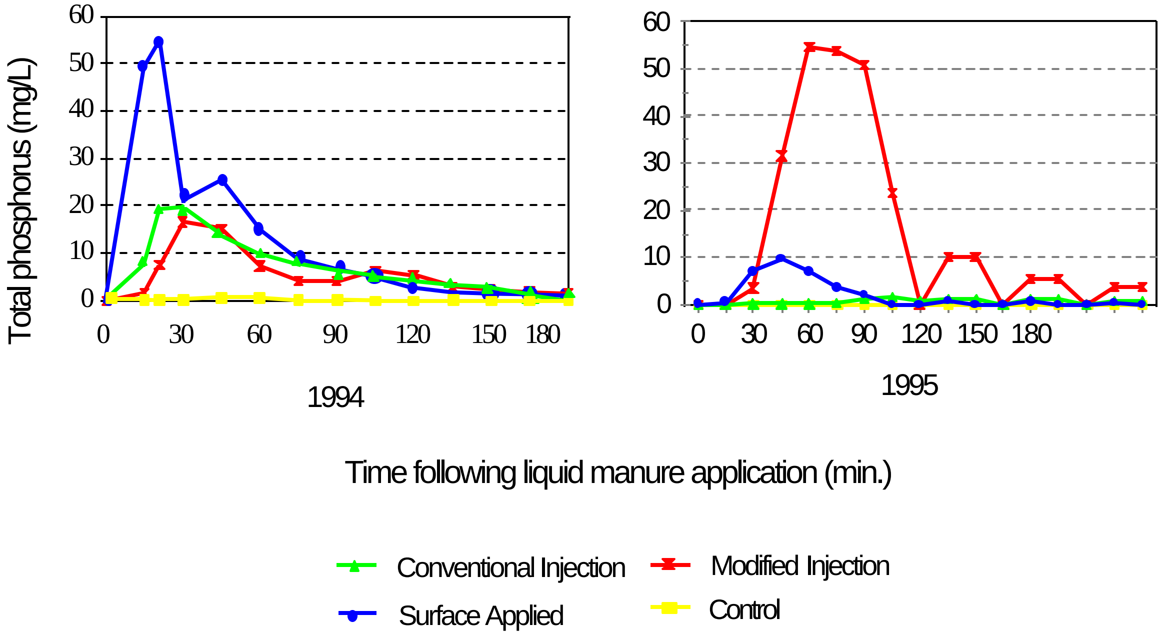

Fig. 8. Total phosphorus concentrations in the tile water following liquid manure application (1994/1995) for Site 1.

In 1994 the chemical tracer strontium-chloride (was added to the manure. Strontium appeared in the tile water under all treatments within 10 minutes following manure application. Values peaked at 35 µg/ml for the surface applied, but concentrations were smaller for the modified injection (19 µg/ml) and conventional injection (25 µg/ml). Strontium concentrations peaked within the first 60 minutes following application. No strontium was detected in the control tiles. The amount of strontium detected in the tiles drains was small relative to the amount applied, for all manure treatments. The greatest amount of applied strontium detected in the tile drain water was 0.08% under the surface applied method.

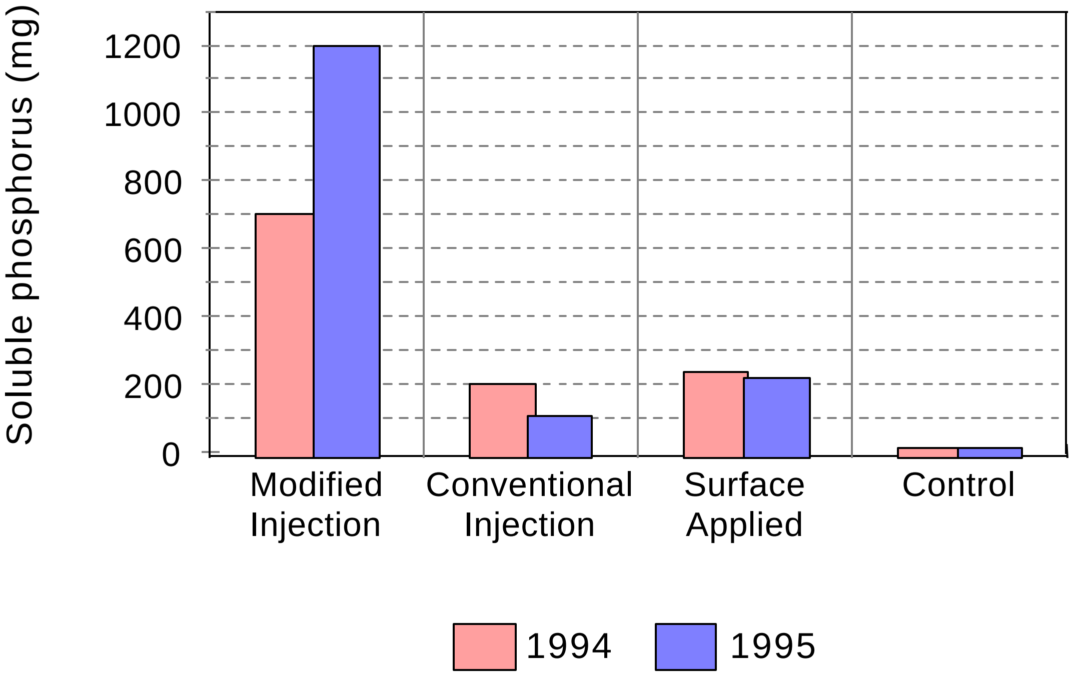

Fig. 9. Soluble phosphorus loadings in the tile water in the 3hr period following liquid manure application (1994/1995) for Site 1.

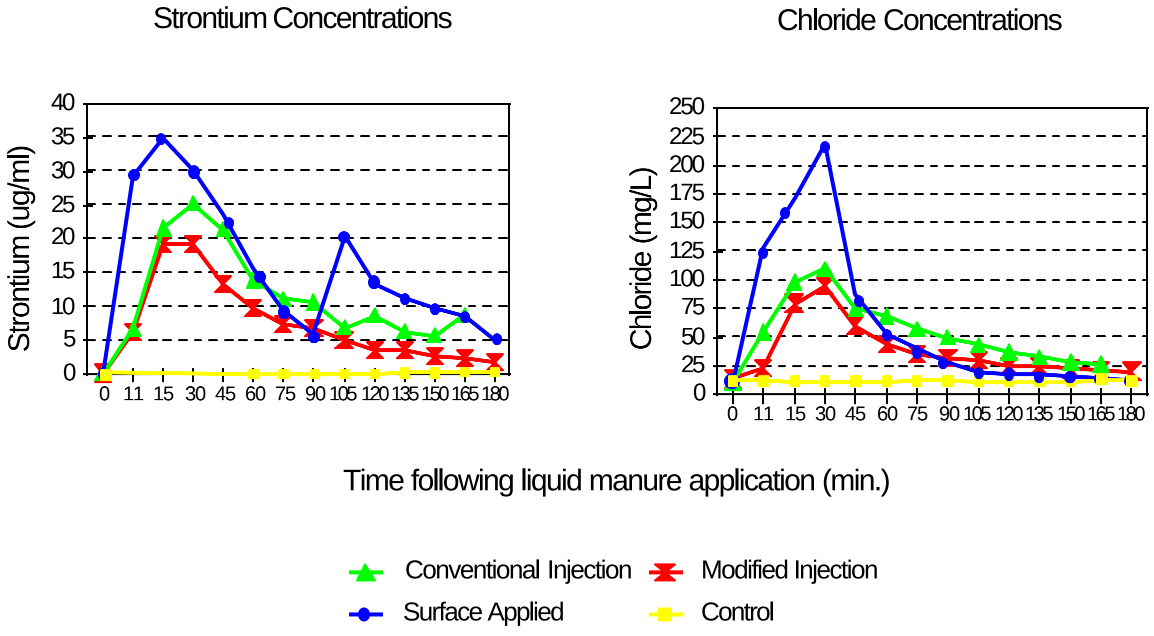

Fig. 10. Strontium and chloride concentrations in the tile water following liquid manure application (1994) for Site 1.

The amount of applied reactive tracer in the tile drain water for the modified injection and conventional injection was relatively small, only reaching 0.04% and 0.03% respectively. Chloride was also present in the tile water within 10 minutes following application. The percentage of applied chloride reaching the tile drains was small for all treatments. Values ranged from a maximum of 2.4% of applied for surface application method to a minimum of 1.8% from the conventional injection. The modified injection tiles contained a total of 2.0% of applied chloride. Strontium and chloride values peaked within 60 minutes for all treatments (Fig. 10).

Soil sampling for strontium was conducted two weeks following manure application. Most of the strontium remained in the upper 30 cm for the modified injection, but the conventional injection and surface applied methods had a significant amount move to the 30 to 60 cm depth or could not be accounted for (Fig. 11). A total of 94% of the applied strontium from the modified injection could be accounted for; however, under the conventional injection and surface applied, we could only account for 49% and 34%, respectively. The lesser values could be a result of poor sampling methods, or the strontium moving below the sampling depths, but remaining in the soil profile.

In 1995, potassium bromide was used as the chemical tracer. Bromide was found in the tile drains within 15 minutes following manure application. Bromide concentrations peaked within 30 minutes of application, but dropped back to small values within 90 minutes. Modified injection resulted in the greatest concentrations of bromide in the tile water, peaking at 2.70 µg/L. Conventional injection and surface applied resulted in much smaller values with concentration in the tile water peaking at 0.50 µg/L and 0.24 µg/L respectively (Fig. 12).

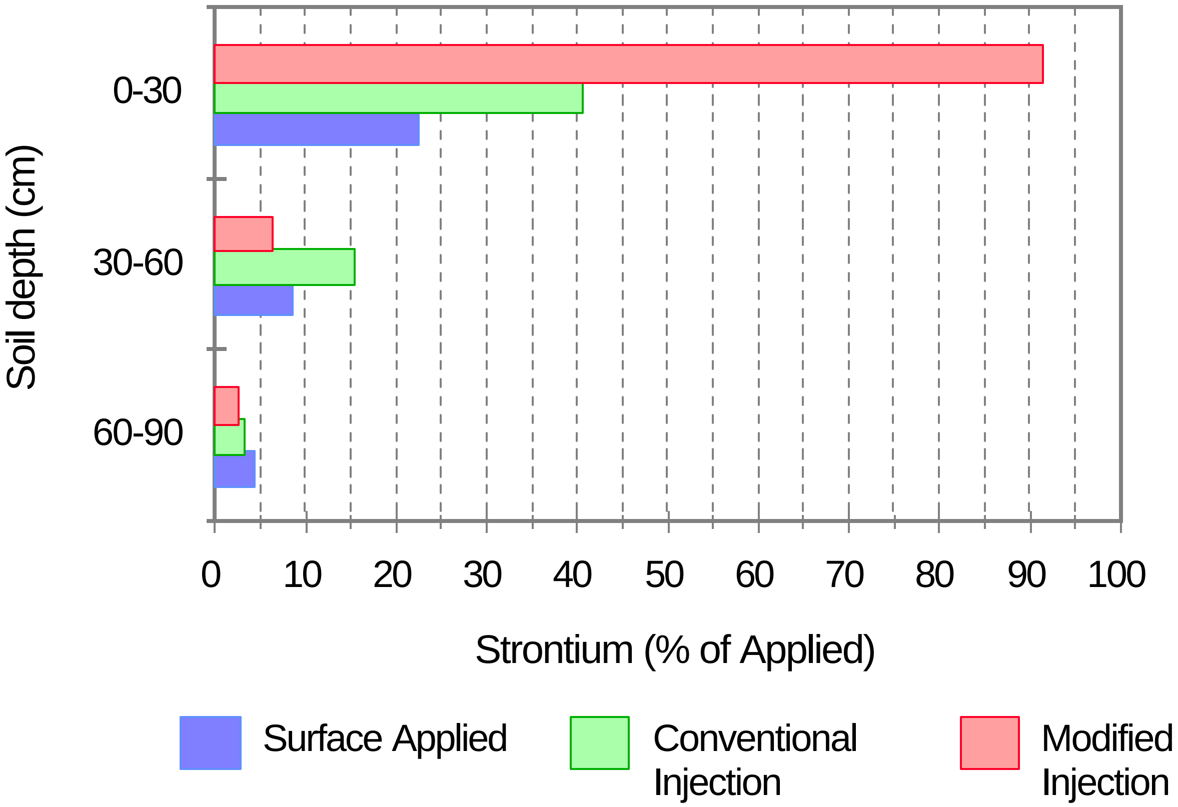

Fig. 11. Strontium content (% of applied) in the soil profile two weeks following liquid manure application (1994) for Site 1.

Bromide loadings were significantly larger for the modified injection application, but present in all treatments (Fig. 13). A small percentage of the applied bromide entered the tile drains during the first three hours following manure application. The largest bromide loadings were found for the modified injection (1.4%). The surface applied and conventional injection treatments had a value of 0.2% of applied reaching the tile drain waters. Significantly smaller background amounts were detected in all tiles.

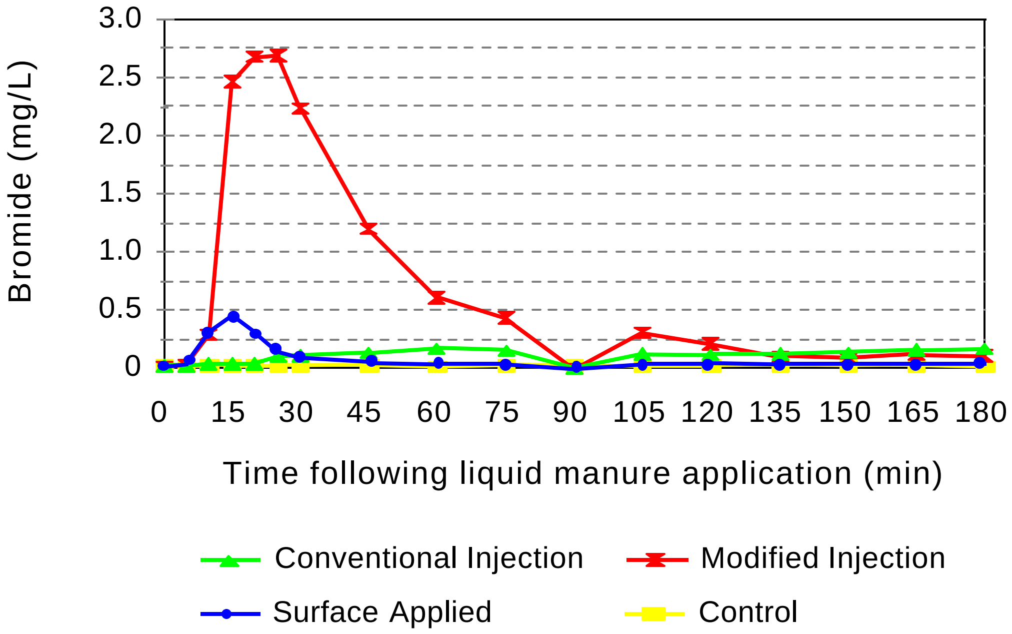

Fig. 12. Bromide concentrations in the tile water following liquid manure application (1995) for Site 1.

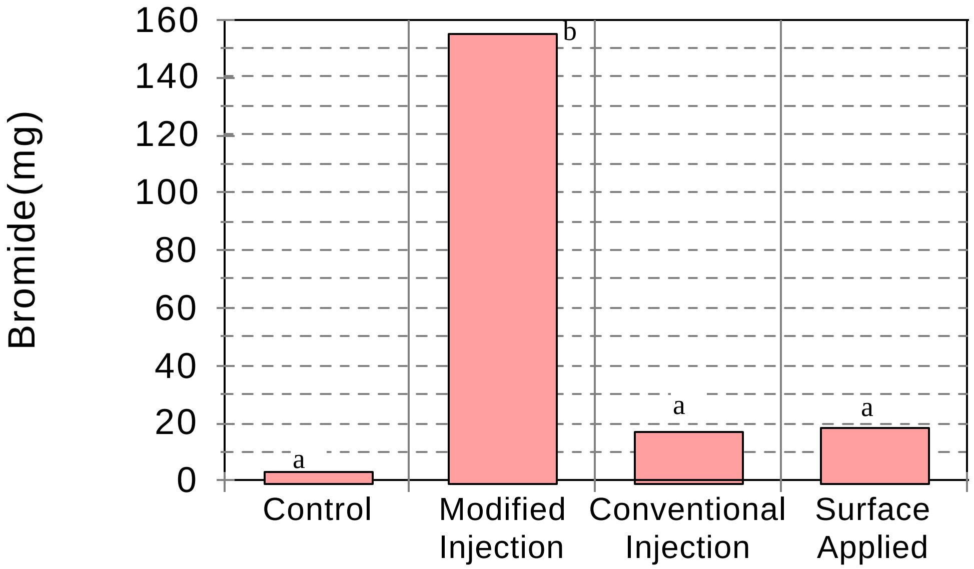

Fig. 13. Bromide loadings in the tile water for the 3hr period following liquid manure application (1995) for Site 1.

Within 12 hours following manure application, ammonium, bacteria and phosphorus concentrations had decreased, but still exceeded water quality standards in both years. Bacteria tracer values averaged around 100 counts/100ml for the three application methods. Ammonium and total phosphorus values averaged 0.05 and 0.07 mg/L respectively. Values remained at these levels until just prior to the rainfall simulation event.

III) Simulated Rainfall Event

In 1995 a simulated rainfall event (3.2 cm over a 3 hour period) was applied 24 hours after manure application. All treatments had an increase in ammonium, phosphorus, bacteria tracer and bromide levels within 30 minutes following the start of the simulated rainfall event, and values peaked within 60 minutes.

Ammonium concentrations in the tile drains were much smaller after the simulated rainfall event compared to those on the day of manure application, with values only reaching a maximum of 5.20 mg/L. Modified injection produced the largest concentrations, followed by conventional injection and surface applied (Fig. 14). The values were not statistically significant at an LSD of 90%. Three hour ammonium loadings were less than half the levels recorded on the day of manure application. Values ranged from a minimum of 1.61 kg for the control site to a maximum of 5.31 kg for the modified injection. The conventional injection and the surface applied had values of 2.04 kg and 1.91 kg respectively. There was no statistical significance at an LSD confidence level of 90%.

Bacteria concentrations were only monitored for the first 30 minutes after the start of the simulated rainfall event. Concentration values were greater following the rainfall event than on the day of manure application for the surface applied treatment, but less for both of the injection methods (Fig. 15). There was no significant difference in the 30 minute bacteria loadings between the three manure application techniques. All treatments were significantly greater than the control plots (Fig. 16).

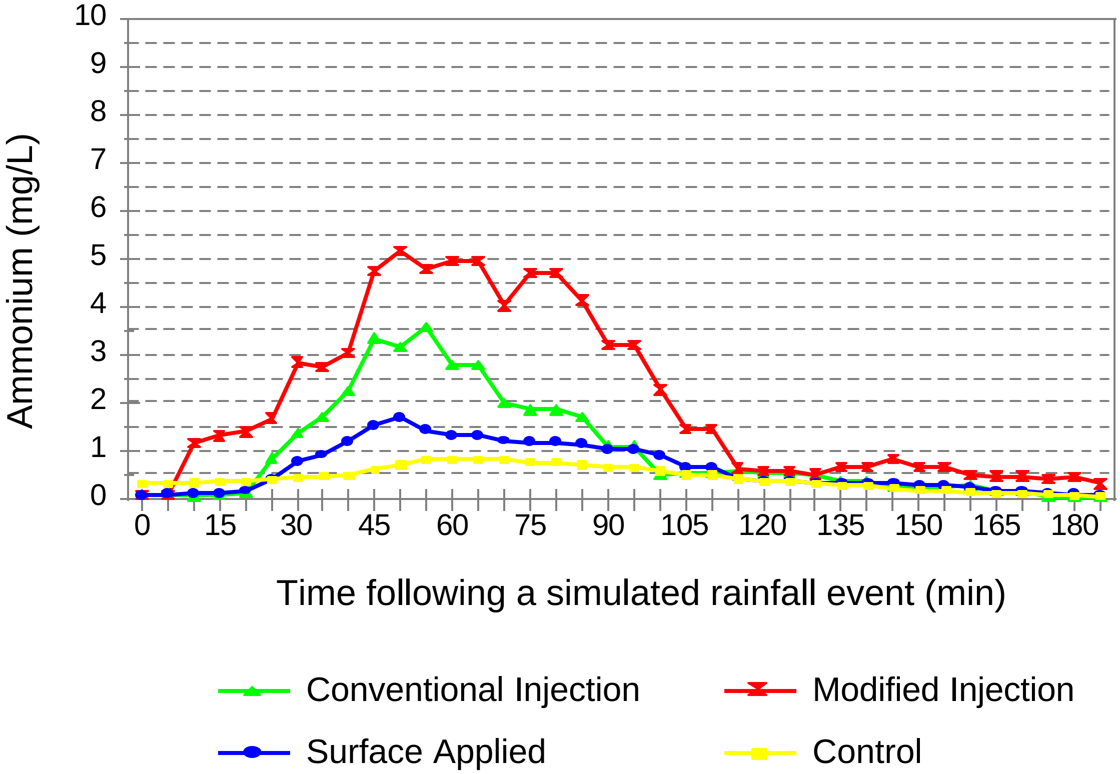

Fig. 14. Ammonium concentrations in the tile water following a simulated rainfall event (1995) for Site 1.

Bromide concentrations were monitored for three hours from the start of the simulated rainfall event. Bromide was detected in all treatments, and values peaked within 60 minutes from the start of the rainfall event and levelled off within three hours. The greatest concentration values were detected under the modified injection method with surface applied and conventional injection being slightly smaller (Fig.17). A small amount of bromide was detected in the control tiles, but not significantly greater than the background levels. The three hour bromide loadings were significantly greater for the modified injection method compared to the conventional injection method, but not significantly greater than the surface applied ($p>0.1$). A greater percentage of applied bromide was flushed through the soil profile with the rainfall event compared to the manure application. A total of 2.7% of applied bromide was flushed through under the modified injection treatment. Smaller amounts of applied bromide were detected under the surface applied and conventional injection with values of 1.9% and 1.3% respectively. Tracer concentrations in the tile water were significantly greater in the manure treatments than the control tiles (Fig.18).

4.14) Agronomic Monitoring

Plant populations at Site 1 did not differ significantly between treatments in both years, with field averages of 66,427 plants/ha (pl/ha) in 1994 and 64,655 pl/ha in 1995 at harvest. Other harvest results indicated an insignificant treatment effect except for some variations in 1995. Lodging (stalks broken below the ear) was significantly less in the surface applied plots (2.7%) than other treatments with the control plots suffering the greatest(11.0%) amount. Grain moisture content, as well as silking date, did not indicate a delay in crop maturity.
The grain moisture of the control plots was least overall (26.6% in 1994 and 23.0% in 1995); however, variation between treatment means was less than 1.2% for both years. At silking time in 1995, leaf tissue analysis of P and K for all plots fell within the normal concentration range. Corn plant nitrogen levels were not significantly different but may have indicated a slight depression with the surface applied treatment (2.58%) being the closest to the 2.5% critical deficiency concentration compared to control (2.72%), conventional injection (2.78%) and modified injection (2.80%) treatments.

Grain yield was not significantly different between treatments in 1994 (average 8.315 t/ha) and 1995 (average 8.023 t/ha). There was not a differentiating trend of yield by treatment over the two years. Yields from surface applied, conventional injection and modified injection plots in 1994 were greater than control plots (16%, 12% and 7% respectively), but in 1995, the yield from the manure applied treatments varied (-10%, 6% and -2% respectively) compared to the control plots. Check plots of no organic or inorganic fertilizer application were not included at Site 1 to determine an accurate crop response to the treatments. However soil nitrogen testing 2 weeks prior to manure application in the manure treatment plots indicated a crop requirement of approximately 70 kg N/ha in 1994 and 1995.

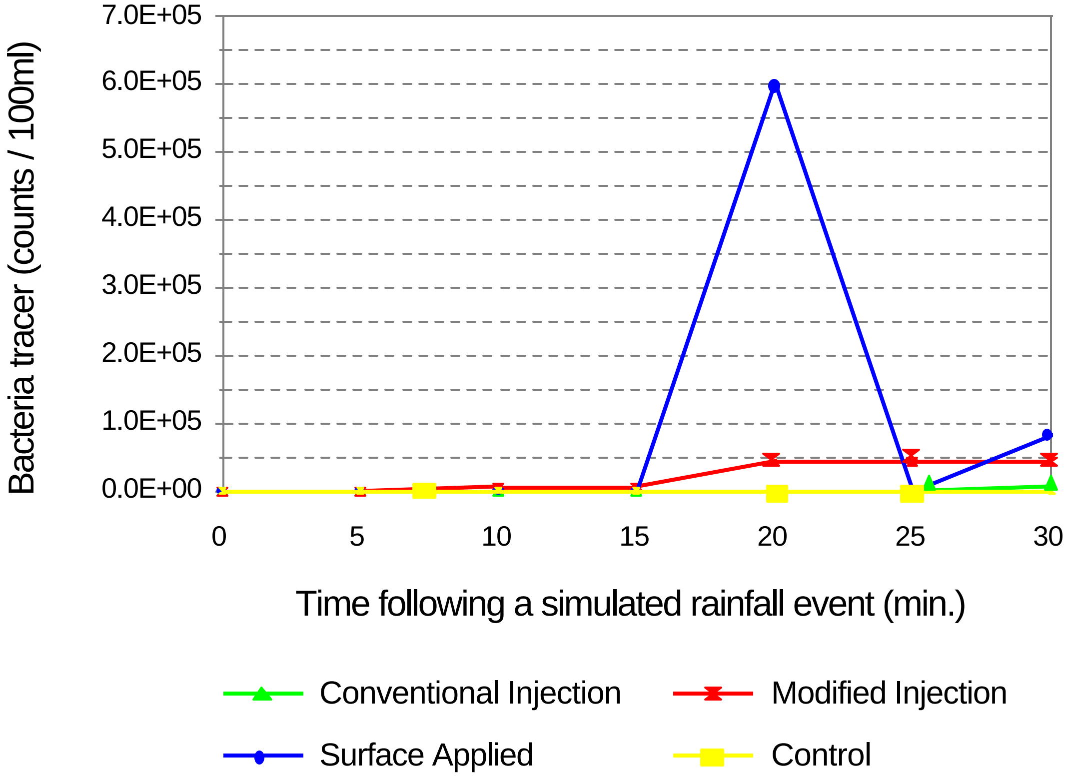

Fig. 15. Bacteria tracer concentrations in the tile water following a simulated rainfall event (1995) for Site 1.

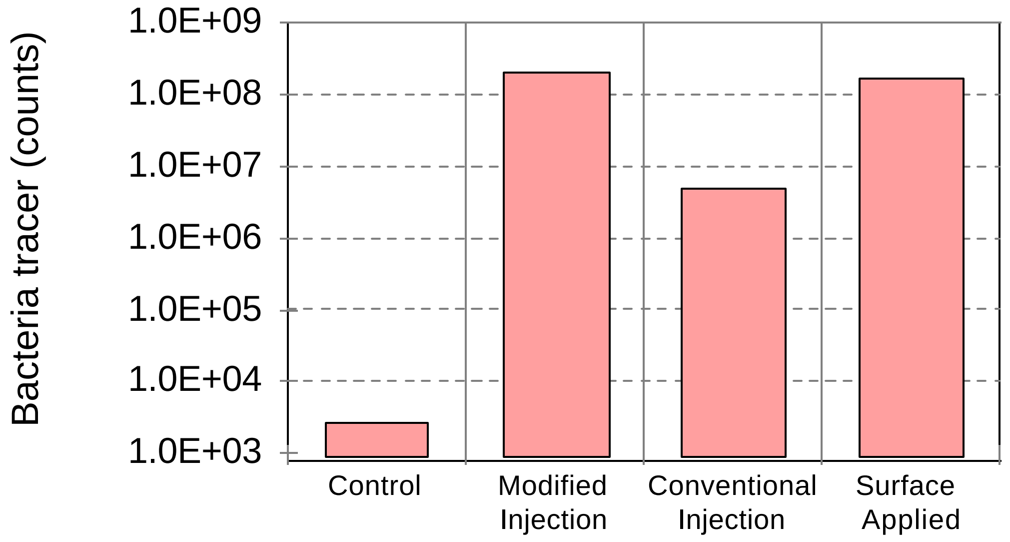

Fig. 16. Bacteria tracer loadings in the tile water for the 3hr period following a simulated rainfall event (1995) for Site 1.

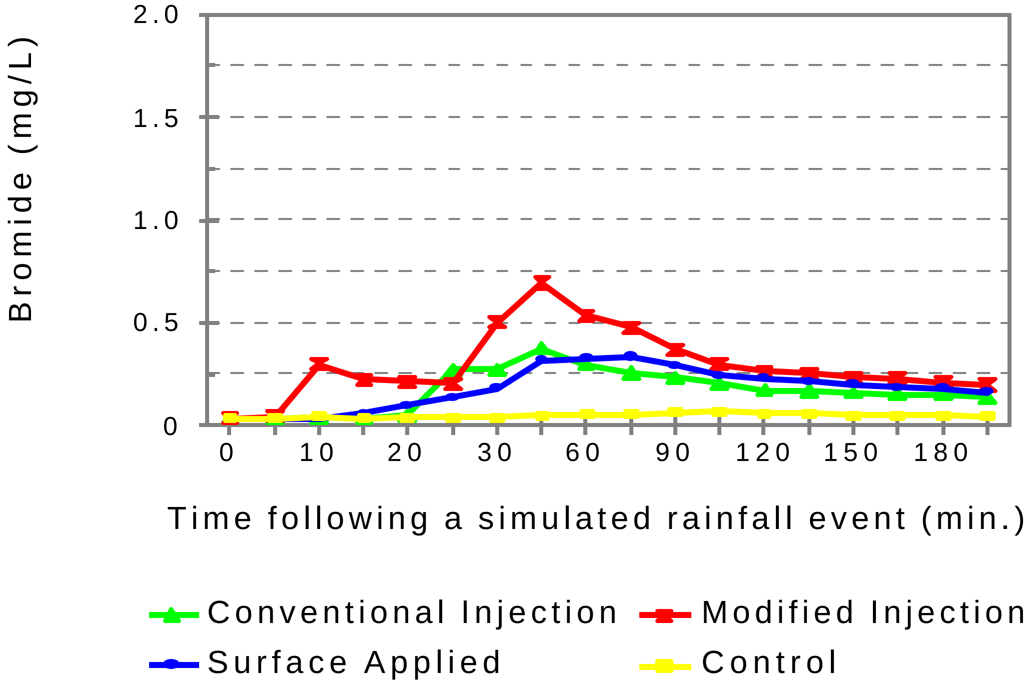

Fig. 17. Bromide concentrations in the tile water following a simulated rainfall event (1995) for Site 1.

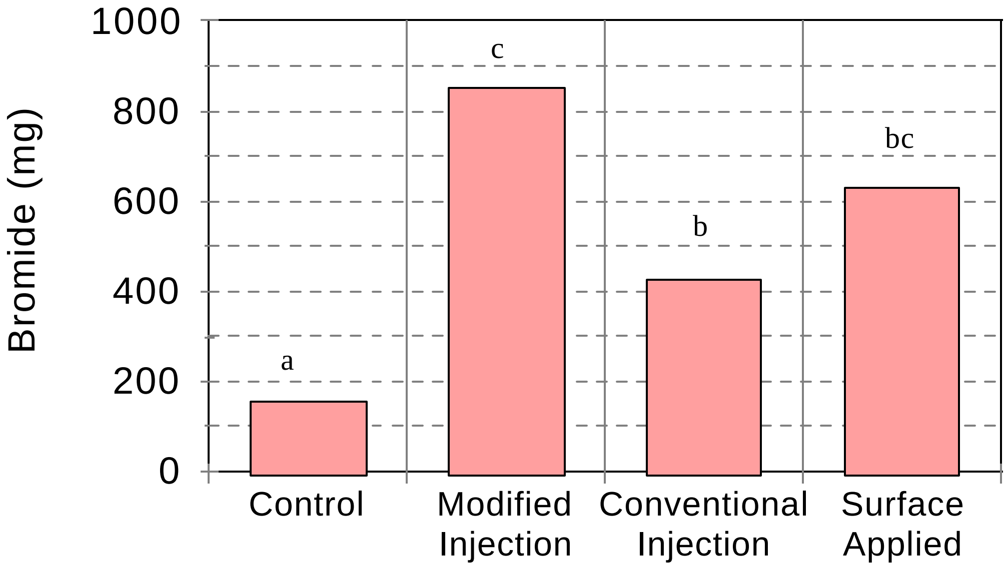

Fig. 18. Bromide loadings in the tile water for the 3hr period following a simulated rainfall event (1995) for Site 1.

Soil nutrient sampling conducted from each tile plot indicated some variability within and between treatments in both years (Appendix E). The findings were not statistically significant with the exception of the control plots (spring inorganic fertilizer) greater nitrogen status just prior to manure application. Soil nitrogen levels two weeks after application reached the desired average of 150 kg N/ha. Soil P and K levels at these sampling times were adequate. Statistical analysis conducted on the agronomic data by comparing treatment means were tested with the least significant difference test at 95% confidence.

4.15 Micro Plot Study

Saturated conditions at an average surface (0-10 cm) volumetric moisture content of 50% was reached within eight days of applying the water. Strontium and chloride were detected in the pan water within three hours following application. Concentrations peaked within fours hours of application and did not return to background levels for several days (Fig. 19). Concentrations as high as 96 mg/L of strontium and 460 mg/L of chloride were detected in the pan water within four hours of application. Within 24 hours, concentrations of strontium and chloride decreased to 12 mg/L and 100 mg/L respectively. Concentrations of chloride in the pan increased again with the addition of water 24 hours following the initial application, but only to 200 mg/L. Strontium concentrations dropped steadily until values were no longer detectable (approximately 16 days). There were slight incremental (30 mg/L) increases in chloride concentrations following each application of water. Within 16 days following application days both strontium and chloride concentrations had receded to baseline levels.

4.2) Study Site 2

4.21) Site Properties

The dominant soil at the Site 2 study location (Putnam) is the imperfectly drained Brisbane soil of the Honeywood association. It has a gravelly subsoil with finer textured material (sandy loam) on the surface.

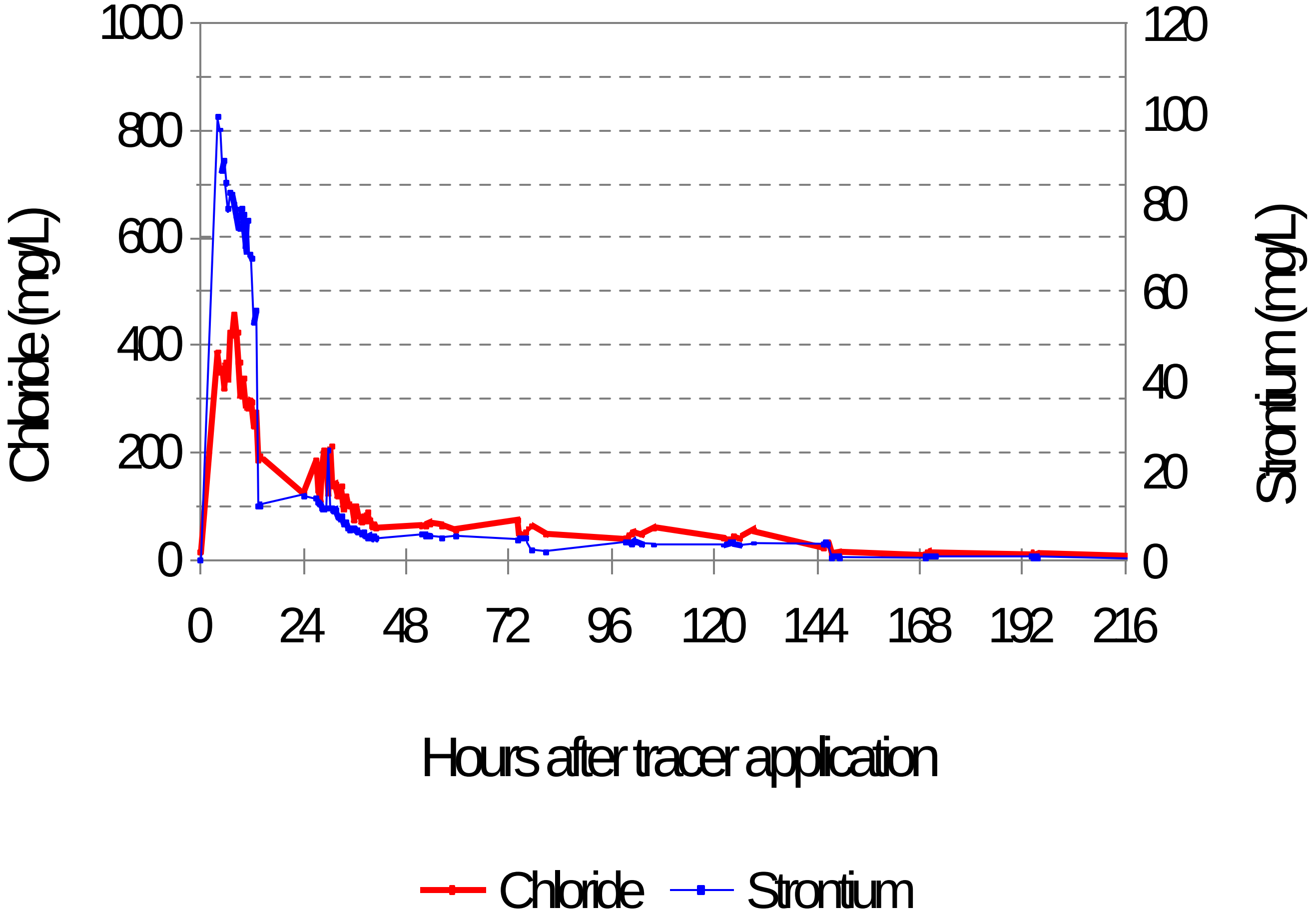

Fig. 19. Strontium and Chloride concentrations in the pan water (1995) for Site 1.

The site has an elevated organic matter content in the surface horizon, averaging 4.4% across the field at the time of the experiment. Detailed soil information is given in Appendix A. The average gravimetric soil moisture across the field ranged from a minimum of 18% to a maximum of 24% with an average moisture content of 21% in 1995. In 1996, the average soil moisture content was slightly greater (25%), with a minimum of 23% and a maximum of 27% across the field.

Penetrometer resistance was measured just prior to the time of manure application. The average value for the field at a depth of 10 cm was 681 kPa in 1995 and 816 kPa in 1996. A measurement at the 30cm depth had an average value for the field of 1278 kPa in 1995 and 1360 kPa in 1996. There was no significant difference (p>0.1) across the field in both years at both depths.

4.22) Tile flow

I) Seasonal

Tile flow for the May to October growing season in 1995 and 1996 is reported in Appendix C. Tile flow was sporadic throughout the year with a rapid response to a rainfall event from early May to early July. In 1995 average tile flow rates peaked at 10.50 L/min in early July following two rainfall events (68 mm and 38 mm) within a few days of each other. Peak flow rates were greater in 1996 with average flows reaching a maximum of 19.12 L/min following a rainfall event of 45 mm in mid May. Tile flow rates declined to average flows of 0.10 L/min or less between rainfall events in 1995 and 1996. In both years from mid July until the end of September, the tiles remained dry even following a rainfall event. Tile flow resumed by the end of October in 1995 with flows peaking at 1.60 L/min. In 1996 tile flow resumed at the end of September and flows peaked at 24.69 L/min. There was no statistical difference (p>0.1) between tiles or treatments in both years.

II) Liquid Manure Application Day

In 1995 there was no tile flow when the liquid manure was applied at a rate of 71,890 L/ha and manure application did not result in tile flow. In 1996 only four of the tiles were flowing prior to manure application, with rates ranging from a maximum of 1.00 L/min to a minimum of 0.10 L/min. Background tile flows and treatments are given in Table 2. The average flow rate for the tiles that were flowing was 0.50 L/min with a standard deviation of 0.58 L/min. There was no significant difference in tile flow between treatments due to the great variability. In 1996 manure applied at a rate of 69,645 L/ha resulted in small increases in some of the tiles which were already flowing, and caused one tile to start flowing. The flow rate increases averaged 0.10 L/min, and all tile flows peaked within the first 45 minutes following manure application (Fig. 20). Tile flows returned to baseline levels within four hours. Manure application did not seem to have an effect tile flow.

Table 2. Tile flow rates for treatments prior to liquid manure application, Site 2

Tile Number	1995		1996	
	Treatment[1]	Flow Rate L/min	Treatment[1]	Flow Rate L/min
1	CO	0.00	MI	0
2	MI	0.00	CI	0.70
3	CI	0.00	SA	0.00
4	SA	0.00	CO	0.10
5	CI	0.00	MI	0.20
6	CO	0.00	SA	0.00
7	MI	0.00	CO	0.00
8	SA	0.00	CI	1.00
9	CI	0.00	MI	0.00
10	MI	0.00	SA	0.00
11	SA	0.00	CO	0.00
12	CO	0.00	CI	0.00

1CO - Control, MI - Modified Injection, CI - Conventional Injection, SA - Surface Applied

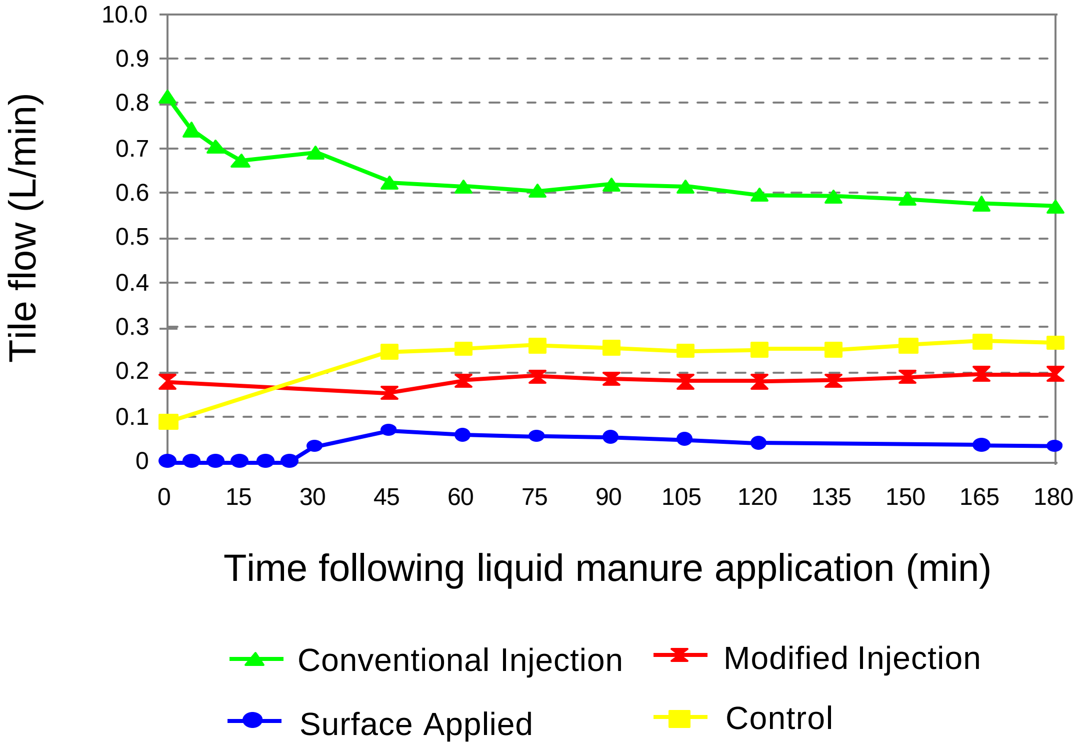

Fig. 20. Tile flow following liquid manure application (1996) for Site 2.

Total three hour flow volumes varied between treatments, but there was no statistical difference. Conventional injection had the greatest total volume with 115.5 L while surface applied had the least total volume at 2.2 L. Modified injection and the control tiles were approximately equal with flow volumes of 11.8 L and 15.1 L respectively. A field average of 0.3% of the volume of applied liquid manure reached the tiles, with the greatest amount, 0.7% from the tiles under conventional injection. The surface applied treatment had an average of 0.3% of the volume of manure reaching the tile drains. There was no increase in tile flow under the modified injection method.

III) Simulated Rainfall Event

On the day of the simulated rainfall event in 1995, a total of 2.6 cm of water was applied to the field over a three hour period (approximately 20-30min duration/tile) using a travelling irrigation gun. The rainfall event resulted in half of the tiles flowing. All of the tiles under the surface applied treatment started to flow while two tiles under the control treatment and one tile under the modified injection treatment started to flow. No tiles under the conventional injection treatment had flow. Tiles started to flow between 30 and 60 minutes following the rainfall event and all flow rates peaked within 135 minutes from the start of the rainfall event. Flow rates returned to baseline levels within 12 hours.

Tile flow rates increased by an average of 5.20 L/min for surface applied, 4.60 L/min for modified injection and 5.20 L/min for the control tiles. Flow rates for the three hour period following the simulated rainfall event are shown in Figure 21. The volumes of applied water reaching the tile drains was relatively small, averaging 1.3% (control - 1.1%, modified injection - 0.5%, conventional injection - 0.0% and surface applied - 2.4%). Total flow volumes in the three hour period following the simulated rainfall event were not significantly different at an LSD confidence level of 90%.

In 1996 a total of 2.8 cm of water was applied to the field. All the tiles started to flow from the simulated rainfall event. Flow rates increased by 22.50 L/min for the conventional injection, 22.00 L/min for the surface applied, 17.50 L/min for modified injection and 22.50 L/min for the control tiles. All flow rates peaked within the first 90 minutes and returned to baseline levels within 24 hours. The volume of applied water reaching the tile drains averaged 12.1% of applied for the entire field. Conventional injection had the greatest volume (14.0% of applied) and modified injection had the least volume (8.1% of applied). Surface applied had a total of 13.2% of applied water and the control tiles averaged 13.0% of applied water reaching the tile drains. The volume of applied water reaching the tile drains was much larger in 1996 than in 1995 due to the greater (~4.0%) antecedent soil moisture in 1996.

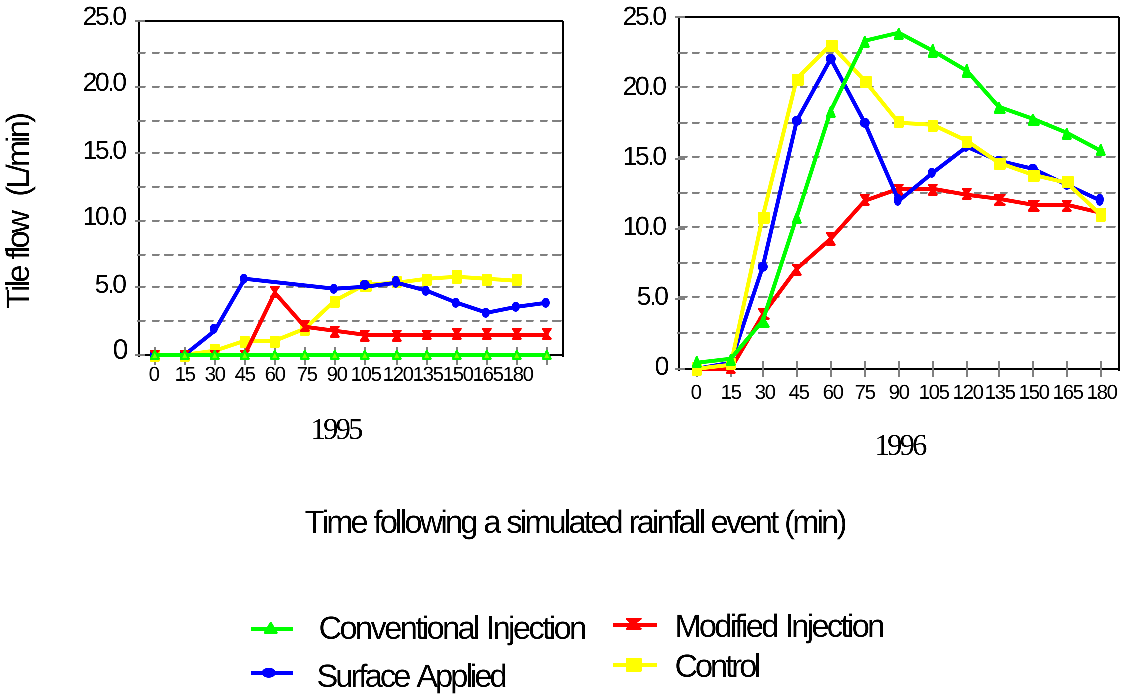

Fig. 21. Tile flow following a simulated rainfall event (1995/1996) for Site 2.

4.23) Water Quality

I) Seasonal

Nitrate concentrations exceeded water quality standards throughout the growing season in 1995, averaging 26.0 mg/L (Appendix D). Nitrate concentrations were slightly larger in the early spring, prior to manure application, averaging around 28.0 mg/L. In 1996 the concentrations were less but still exceeded water quality standards, averaging 15 mg/L. The tile nitrate concentrations were not significantly affected by the application of manure. Concentrations of total phosphorus usually exceeded the water quality standards in both years with concentrations ranging from 0.10 mg/L to 1.2 mg/L for all treatments. Soluble phosphorus concentrations remained constant throughout the growing season with concentrations averaging 0.05 mg/L. There was no significant difference ($p>0.1$) between treatments for all nutrients in both years.

II) Liquid Manure Application Day

In 1996, concentrations of ammonium, phosphorus, and bacteria increased within three hours following manure application from the few tiles which were flowing (data available in COESA Rep. # RES/MON-009/97 - Agriculture and Agri-Food Canada, 1997). Manure contamination of the tile drains was not as visually evident at this site as it was at the loam soil site, but there was a slight colour change in the tile water under some of the tiles. The chemical tracer bromide was also detected in the tile water within three hours following application. Data for surface applied and modified injection are only taken from one tile. Data from the conventional injection is the average of three tiles.

Ammonium concentrations increased within 75 minutes following application under all treatments in 1996, exceeding aquatic water quality standards (1.37 - 2.2 mg/L)(Fig 22). The maximum concentration of 69.6 mg/L was seen under the surface applied method. Much smaller concentrations were detected under the conventional injection (15.6 mg/L) and the modified injection methods (3.3 mg/L). The levels in the control tiles did not change. Ammonium concentrations decreased to background levels within 12 hours following manure application.

Ammonium loadings in the tile water were calculated for a three hour period following manure application in 1996. Total loadings of ammonium were greatest for conventional injection (585.2 mg), followed by surface applied (73.2 mg) and modified injection (13.3 mg). There was a small amount of ammonium present in the control tile (4.7 mg). The conventional injection was significantly greater than the modified injection and the control tiles; however it was not significantly greater than the surface applied ($p>0.1$)(Fig. 23).

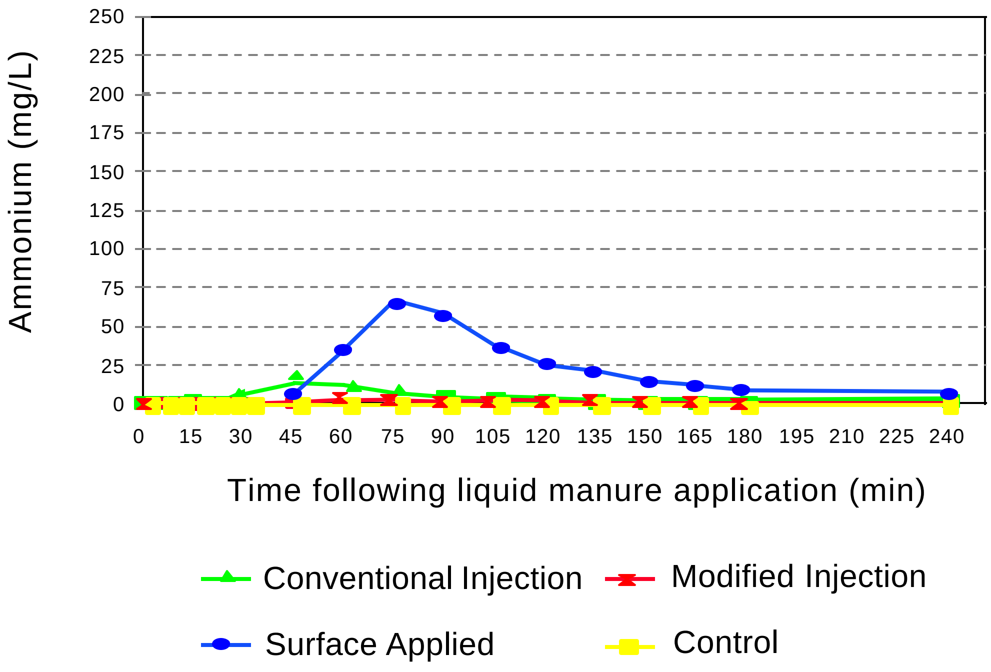

Fig. 22. Ammonium concentration in the tile water following liquid manure application (1996) for Site 2.

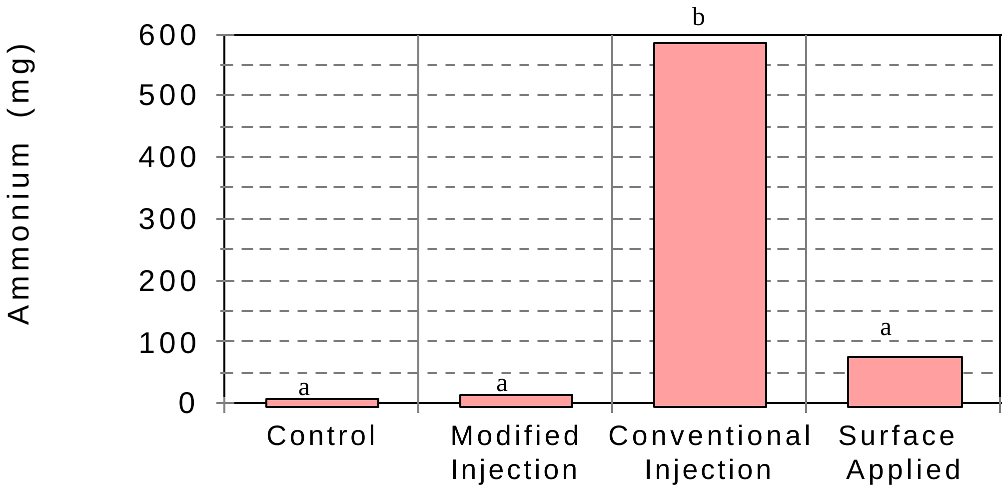

Fig. 23. Ammonium loadings in the tile water for the 3hr period following liquid manure application (1996) for Site 2.

In 1996, bacteria tracer (E.coli) concentrations in the tile water exceeded drinking water quality standards (0 counts/100ml) within 15 minutes following manure application and peaked within 120 minutes after application for all treatments. Bacteria tracer levels increased from 0 counts/ml for all treatments to 4.9 x 10^4 counts/ml for conventional injection, 5.0 x 10^3 counts/ml for modified injection and 6.5 x 10^4 counts/ml for surface applied (Fig. 24).

Bacteria loadings were calculated in 1996 for a three hour period following manure application. There was no significant difference between treatments, although the tiles under conventional injection had much greater bacteria loadings than the surface applied and the modified injection (Fig. 25). The lack of significant difference is due to the great variability in the tile flow.

In 1996, manure application resulted in greater total phosphorus concentrations under all application methods, with all treatments exceeding water quality standards. The greatest increase was seen under the surface applied with concentrations reaching 3.8 mg/L. Conventional injection and modified injection had smaller peaks of 2.1 mg/L and 0.2 mg/L, respectively (Fig. 26).

Soluble phosphorus concentrations also increased following manure application. Surface applied had the greatest concentrations (2.1 mg/L) followed by conventional injection (1.4 mg/L) and modified injection (0.06 mg/L). Total phosphorus and soluble phosphorus loadings were calculated for a three hour period following manure application (Fig 27). Conventional injection was significantly greater than the modified injection and the control tiles for both nutrients due to the greater tile flow under conventional injection.

In 1996, potassium bromide was added to the manure prior to application. Bromide concentrations were monitored for three hours following application. It was detected in the tile drains within 45 minutes from the time of manure application. Bromide concentrations peaked within 75 minutes of application but dropped back to very small values within 150 minutes. The surface applied treatment resulted in the greatest concentration of bromide with concentrations peaking at 0.31 mg/L. Bromide concentrations in the tiles under conventional injection and modified injection were smaller at 0.27 mg/L and 0.02 mg/L respectively (Fig. 28). The amount of bromide actually reaching the tile drain water was relatively small, with less than 1% (surface applied-0.002%, modified injection-0.001%, conventional injection-0.02%) detected in the tile drains. Three hour bromide loadings were greater for the conventional injection method, but not statistically different ($p>0.1$) (Fig. 29).

Within 12 hours following manure application, ammonium, bacteria and phosphorus levels had decreased to background levels. Bromide was still detectable in some of the tiles, but at very low levels (0.01 mg/L).

III) Simulated Rainfall Event

In 1995 and 1996 following the simulated rainfall event, all treatments which had tile flow had increased levels of ammonium, phosphorus, bacteria tracer and bromide

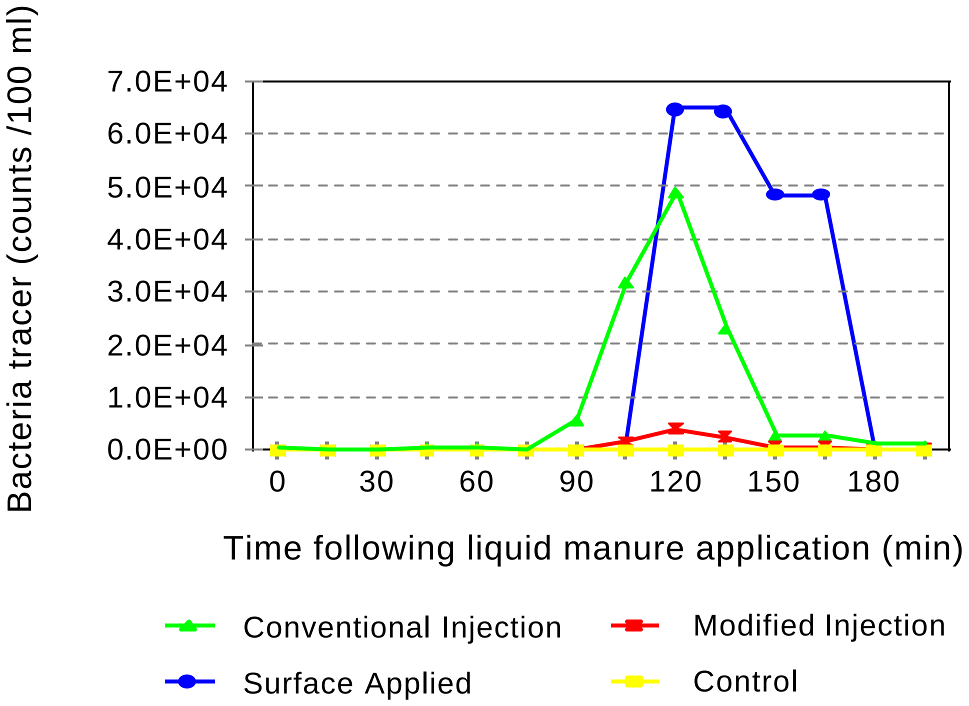

Fig. 24. Bacteria tracer concentrations in the tile water following liquid manure application (1996) for Site 2.

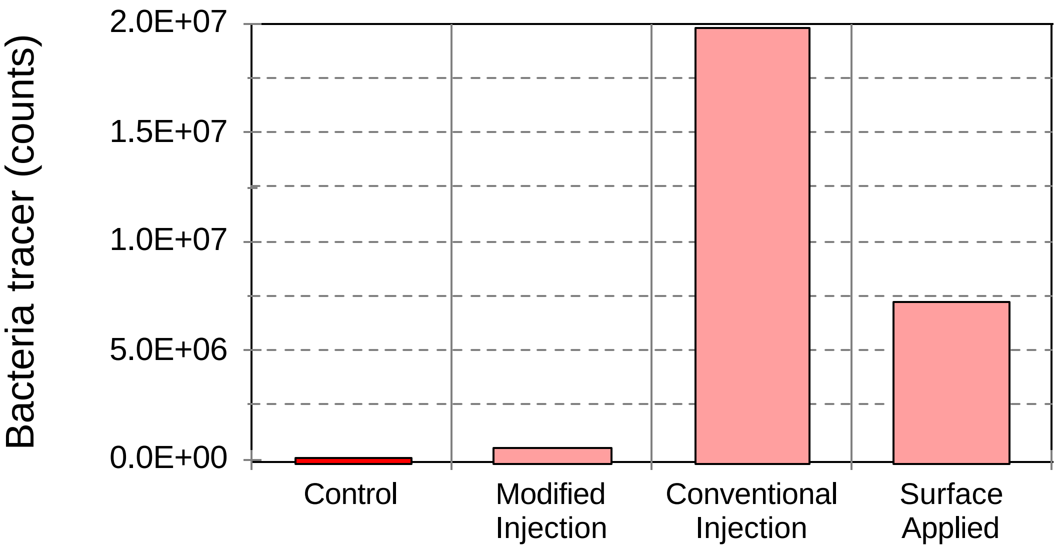

Fig. 25. Bacteria tracer loadings in the tile water for the 3hr period following liquid manure application (1996) for Site 2.

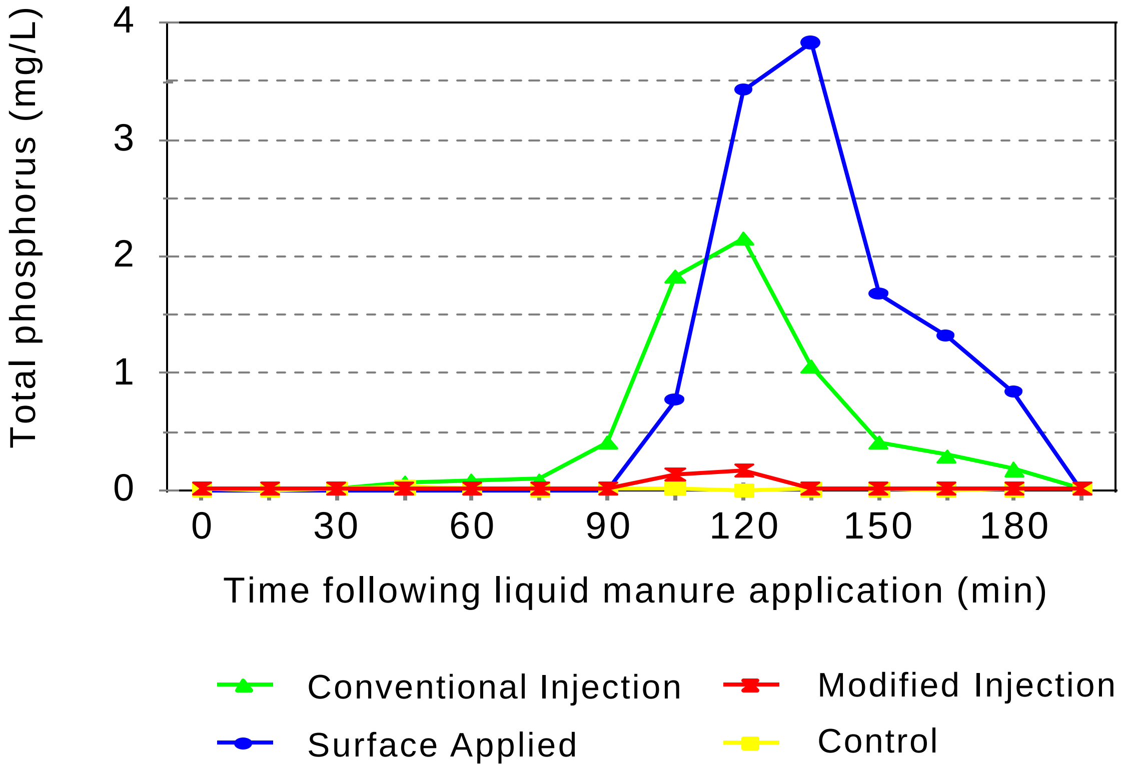

Fig. 26. Total phosphorus concentration in the tile water following liquid manure application (1996) for Site 2.

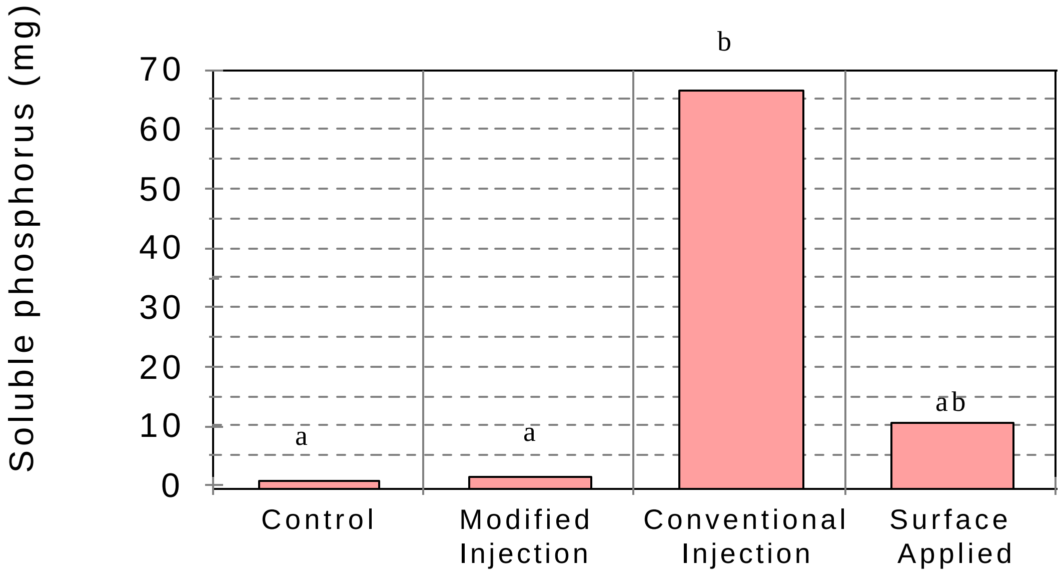

Fig. 27. Soluble phosphorus loadings in the tile water for the 3hr period following liquid manure application (1996) for Site 2.

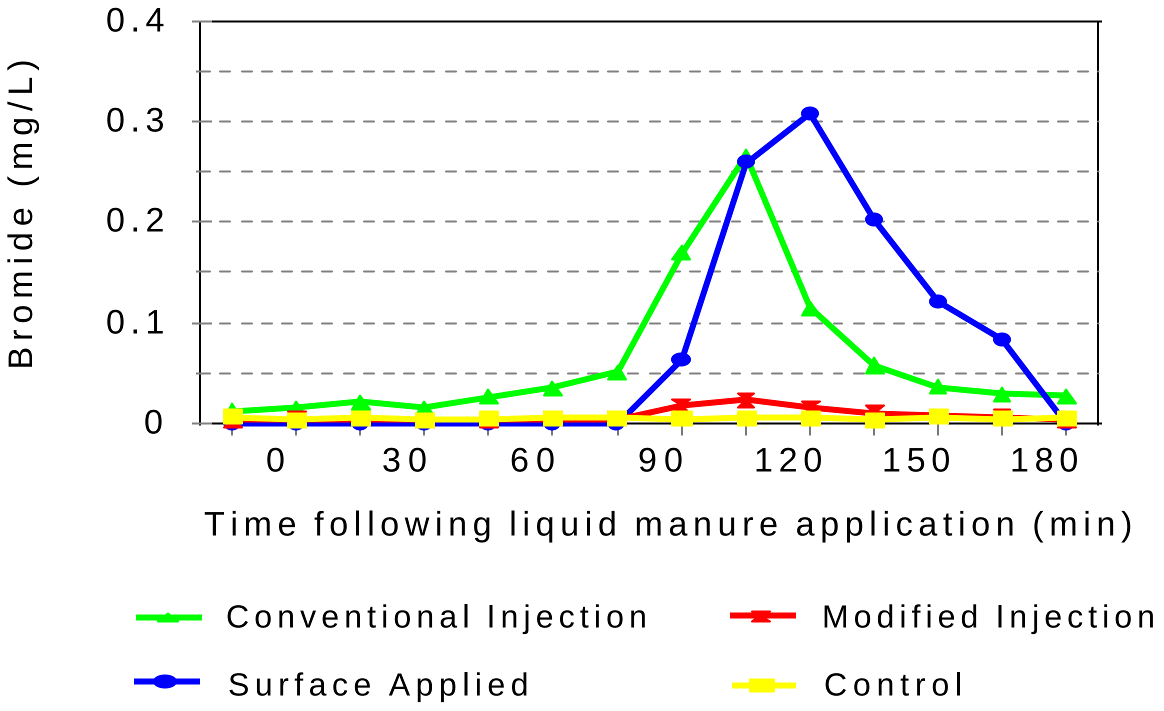

Fig. 28. Bromide concentrations in the tile water following liquid manure application (1996) for Site 2.

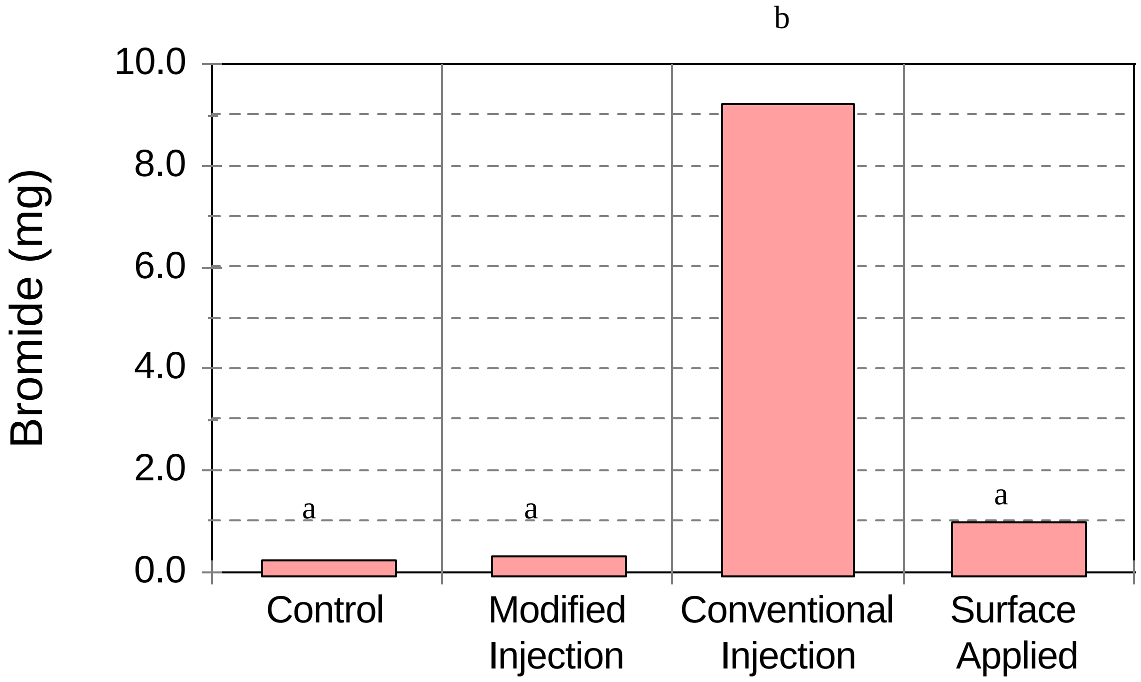

Fig. 29. Bromide loadings in the tile water for the 3hr period following liquid manure application (1996) for Site 2.

concentrations in the tile water within 30 minutes, and peaked within 60 minutes (data available in COESA Rep. # RES/MON-009/97 - Agriculture and Agri-Food Canada, 1997).

In 1995 ammonium concentrations were smaller overall on the day of the simulated rainfall event but still exceeded aquatic water quality standards with concentrations reaching a maximum of 5.2 mg/L. Surface applied had the greatest concentrations followed by modified injection and the control tiles (Fig 30). There was no ammonium from the conventional injection treatment due to lack of tile flow. The ammonium concentrations were not statistically significant ($p>0.1$).

Ammonium loadings in the tile water varied between treatments, ranging from a minimum of 0 kg for the conventional injection site to a maximum of 0.49 kg for the surface applied tiles. The modified injection and the control tiles had loadings of 0.12 kg and 0.015 kg respectively. There was no statistical significance ($p>0.1$) due to larger variations in tile flow.

In 1996, ammonium concentrations in the tile water increased following the simulated rainfall event, but again were much smaller than on the day of manure application. The greatest concentrations were recorded from the surface applied method (5.8 mg/L) and the smallest concentrations were from the modified injection method (2.1 mg/L). The conventional injection and the control tiles had concentrations of 2.6 mg/L and 2.8 mg/L respectively (Fig. 30). All concentrations peaked within the first 45 minutes from the start of the rainfall event and receded to baseline levels within 12 hours following manure application. Ammonium loadings were much greater in 1996 than 1995 due to the larger tile flows ranging from a maximum of 4.450 kg under the surface applied to a minimum of 0.986 kg under the modified injection method. The conventional injection loading washed 2.13 kg while the control tiles loadings was 1.68 kg. The surface applied was significantly greater than either of the injection methods and the control at an LSD confidence level of 90%.

In 1995, bacteria tracer concentrations in the tile water were monitored for three hours following the simulated rainfall event. Surface applied had the greatest concentrations, peaking at 1.75 x 10^5 counts/100ml within 60 minutes. Modified injection was similar with concentrations of 1.6 x 10^5 counts/100 ml. A small amount of bacteria tracer was detected under the control tiles (<1.0 x 10^3 counts/100ml) (Fig. 31). In 1996, bacteria tracer concentrations were less following the rainfall event than on the day of manure application for all treatments. Concentrations ranged from a maximum of 1.52 x 10^5 counts/100ml for the surface applied to a minimum of 3.0 x 10^4 counts/100ml for both the conventional and the modified injection methods. No bacteria tracer were detected in the control tiles (Fig. 31). All treatment concentrations peaked within the first 45 minutes following the start of the rainfall event, and receded to baseline levels within 12 hours. Bacteria loadings were also determined for 1995 and 1996. The surface applied treatment had statistically greater amounts of bacteria tracer present than either of the injection methods in 1996; however the injection methods were not significantly greater than the control tiles (Fig. 32). There was no statistical difference ($p>0.1$) between any of the treatments in 1995.

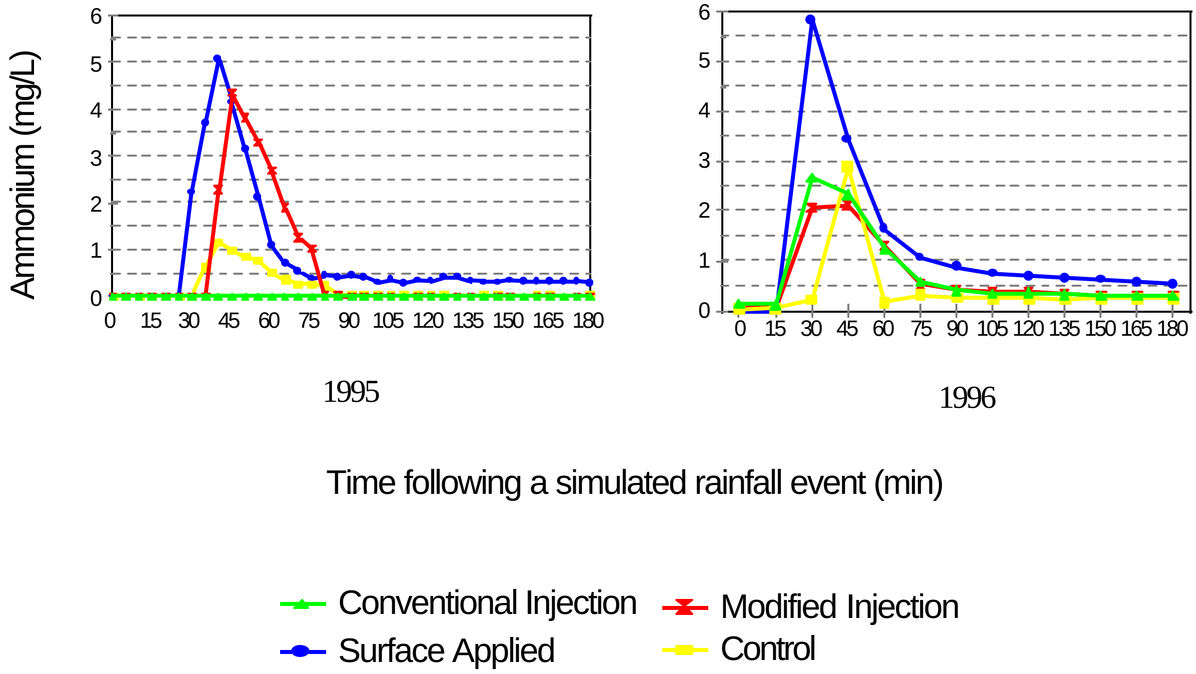

Fig. 30. Ammonium concentrations in the tile water following a simulated rainfall event (1995/1996) for Site 2.

Total phosphorus and soluble phosphorus concentrations increased and exceeded water quality standards following the simulated rainfall event in both years. Total phosphorus concentrations peaked within 45 minutes reaching 1.7 mg/L for surface applied and 3.3 mg/L for modified injection in 1995. In 1996, the concentrations were slightly greater, reaching 5.5 mg/L for surface applied. Concentrations under both injection methods were much less, at 2.3 mg/L and 1.2 mg/L for conventional injection and modified injection respectively (Fig. 33). Soluble phosphorus concentrations also increased following the simulated rainfall event, peaking at 3.3 mg/L for the surface applied treatment, 0.8 mg/L for conventional injection and 0.5 mg/L for modified injection, but all treatments declined to background levels within 12 hours following the rainfall event. Soluble phosphorus loadings were greater in 1996 than in 1995 due to large tile flow volume. In 1995 there was no significant difference between treatments, but in 1996 the surface applied method was significantly greater than the control tiles and both injection methods (Fig 34).

Tile water bromide concentrations were monitored from the start of the simulated rainfall event for three hours. In 1995, bromide was detected in all tiles that had flow. Concentrations peaked within 45 minutes from the start of the rainfall event. The largest concentrations were observed with the surface applied method, followed by the modified injection method. There was a trace of bromide found in the control tiles which could be from natural occurring sources, or from some cross contamination from the other treatments (Fig. 35). The amount of bromide flushed through to the tile drains was relatively small (surface applied - 0.29%, modified injection - 0.20%). Bromide loadings for the three hour period following rainfall simulation were not significantly different ($p>0.1$) between treatments due to the large variations in tile flows (Fig. 36).

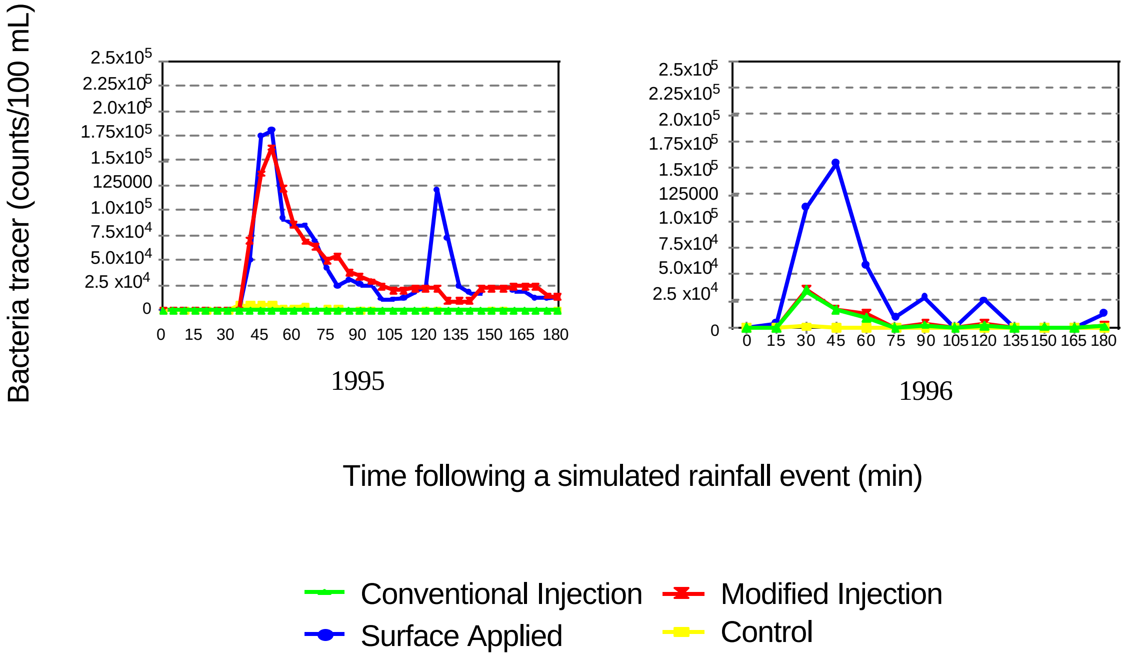

Fig. 31. Bacteria tracer concentrations in the tile water following a simulated rainfall event (1995/1996) for Site 2.

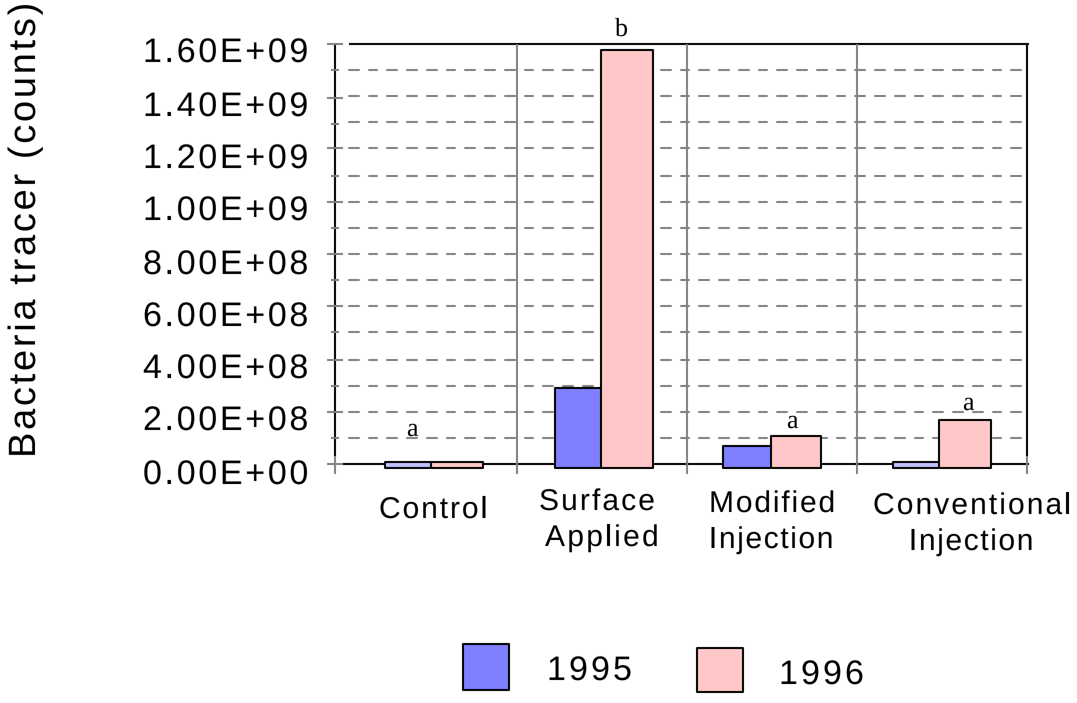

Fig. 32. Bacteria tracer loadings in the tile water for the 3hr period following a simulated rainfall event (1995/1996) for Site 2.

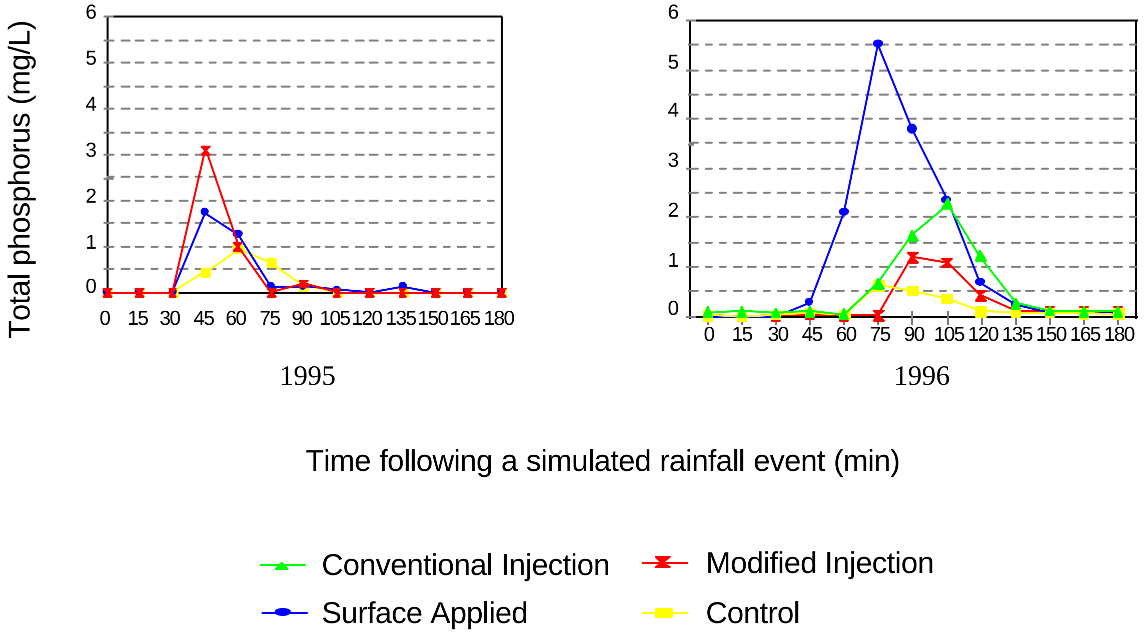

Fig. 33. Total phosphorus concentrations in the tile water following a simulated rainfall event (1995/1996) for Site 2.

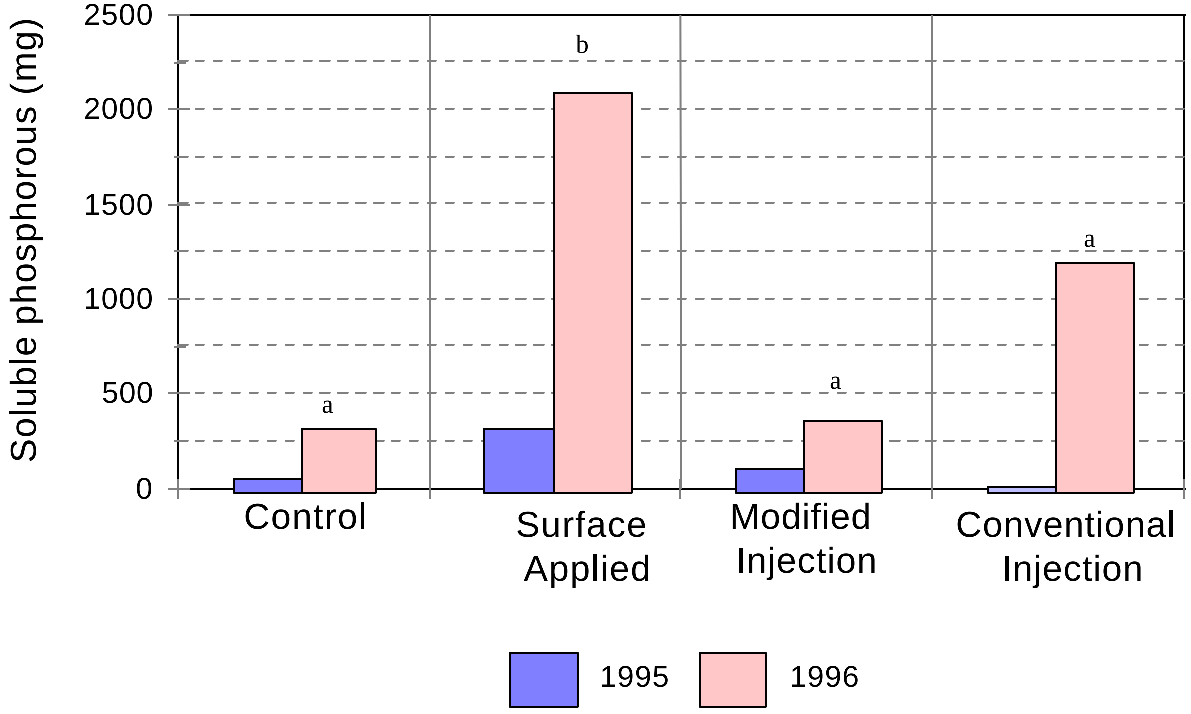

Fig. 34. Soluble phosphorus loadings in the tile water for the 3hr period following a simulated rainfall event (1995/1996) for Site 2.

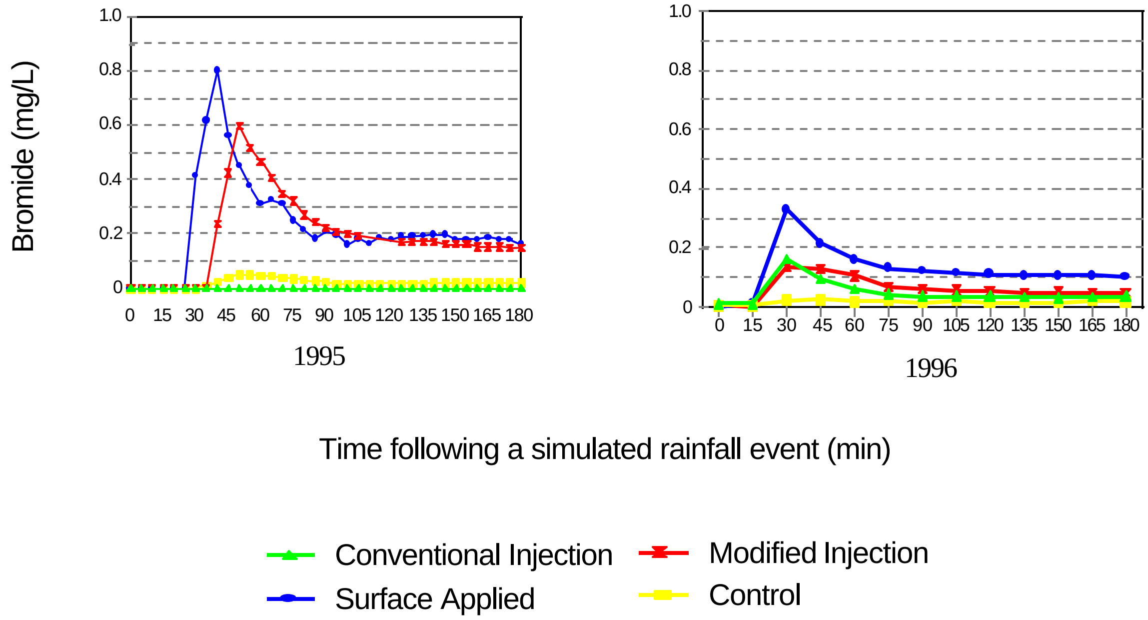

Fig. 35. Bromide concentrations in the tile water following a simulated rainfall event (1995/1996) for Site 2.

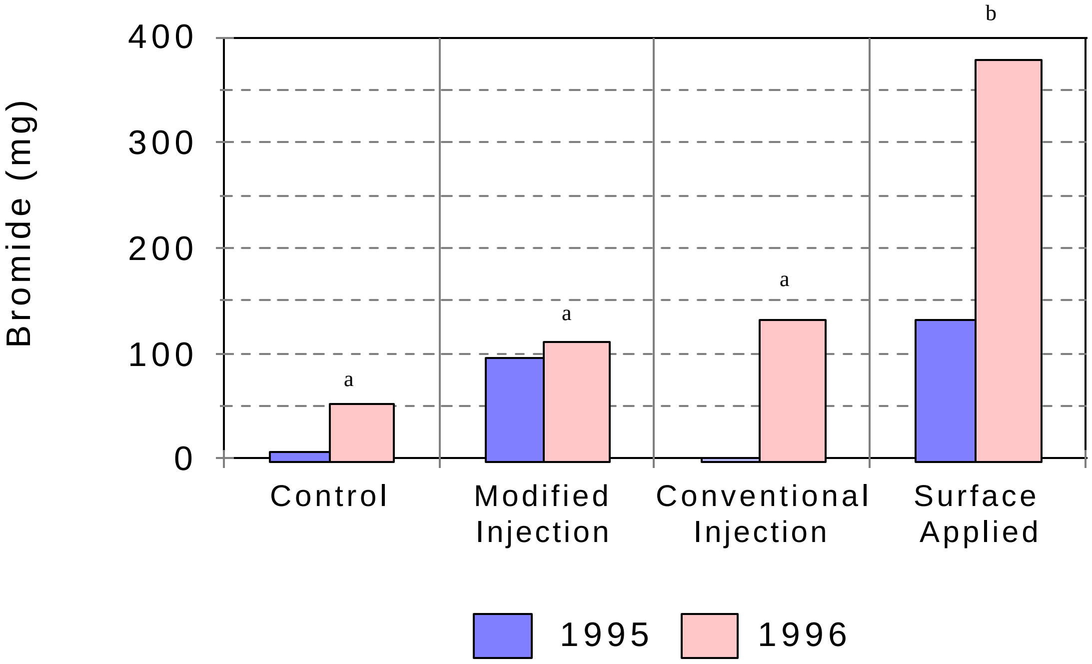

Fig. 36. Bromide loadings in the tile water for the 3hr period following a simulated rainfall event (1995/1996) for Site 2.

In 1996, bromide was detected in all the tiles but at smaller concentrations than in 1995. Surface applied had the largest concentrations at 0.32 mg/L, while modified injection had the lowest concentrations at 0.12 mg/L. The conventional injection was slightly larger, peaking at 0.15 mg/L (Fig. 35). There was a trace amount(above background levels) from the control tiles. The amount of bromide reaching the tile drain water was slightly greater following simulated rainfall compared to the day of manure application but still relatively small (surface applied - 0.84%, modified injection - 0.24%, conventional injection- 0.29%). All concentrations peaked within 30 minutes and returned to baseline levels within 12 hours following the simulated rainfall event. Bromide loadings were calculated for a three hour period following the simulated rainfall. Significantly greater amounts of bromide were measured in the tile water from the surface applied treatment than either injection method. Values range from a maximum of 470 mg to a minimum of 50 mg (Fig. 36).

4.24) Agronomic Monitoring

The corn crop response to the manure application and inorganic fertilizer control treatments over the two years at Site 2 was inconsistent. Final plant populations differed between treatments in both years as control plots were significantly less (60,260 pl/ha) than the other treatments in 1995 and significantly greater (72,207 pl/ha) in 1996. The smaller plant populations in the manure applied plots in 1996 was an indication of damage caused by manure application equipment. Plant tissue analysis at silking indicated nitrogen levels slightly below (<0.2%) the critical concentration of 2.5% for the manure treatments in 1995 but not in 1996. Crop lodging was not different within either year; however, in 1995, field averages were greater than 18%.

Grain moisture content at harvest in 1995 was essentially the same, as treatment means were within 0.6% of each other. Significant difference was found in 1996 with the conventional injection (26.0%) and modified injection (26.5%) methods being greater than control plots (24.2%). Grain yield was not significantly different between treatments in 1995 (field average of 9.101 t/ha). Yields in 1996 may have been reduced in manure treatments from plant damage during application. Surface applied, conventional injection and modified injection plots had smaller yields (33%, 9% and 10% respectively) than the control plots (8.454 t/ha); however the only plots significantly less ($p>0.1$) were the surface applied treatment and check strips (6.802 t/ha) which were monitored to determine crop response to the residual soil nutrients.

Soil testing two weeks prior to manure treatments indicated approximately 85 kg N/ha of crop nitrogen requirement for the manure treatments in both years. Soil P and K levels suggested a minimal crop requirement. Soils were again sampled in late July or early August approximately two weeks after manure application. At this sandy loam site these results revealed nitrate nitrogen levels below the mid June values in both years. Nitrate levels in the control plots remained significantly greater than those in the manured plots. This loss of nitrogen is partially attributable to crop uptake and may in part be due to leaching of this mobile nutrient from above average rainfall.

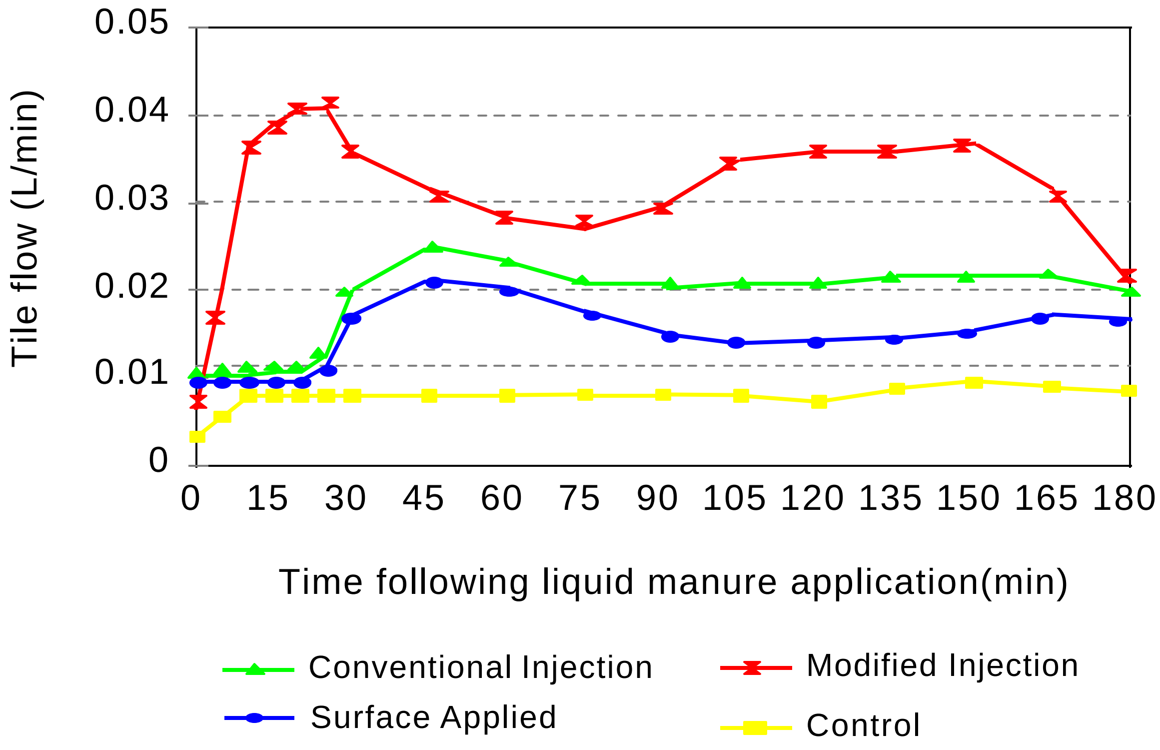

Fig. 37. Tile flow following liquid manure application (1996) for Site 3.

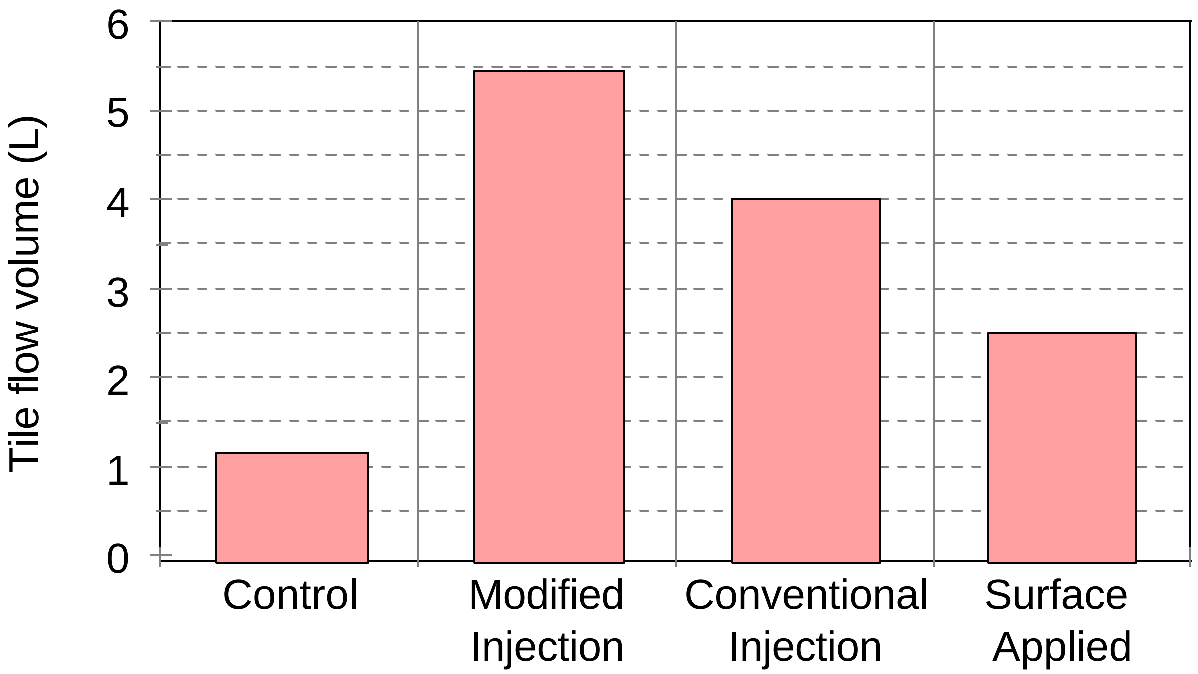

Fig. 38. Total tile flow volumes for the 3hr period following liquid manure application (1996) for Site 3.

4.30) Study Site 3

4.31) Site Properties

The predominant soil at Site 3 (Strathroy) is the imperfectly drained Perth soil of the Huron association. It is comprised of a silt loam, loam or silty clay loam surface over top of a silty clay loam till. The site averages 3.1% organic matter in the surface horizon. Detailed soil information is given in Appendix A. The average gravimetric soil moisture across the field on the day of manure application ranged from a low of 16% to a high of 27% with an average moisture content of 22%.

Penetrometer resistance was measured at four depths just prior to the time of manure application. The average value for the field at a depth of 5 cm was 656 kPa, while the resistance at 10 cm, 15 cm and 20 cm were 1710 kPa, 1373 kPa and 1077 kPa respectively. There was no significant difference ($p>0.1$) across the field.

4.32) Tile Flow

I) Seasonal

Tile flow for the May to August period was sporadic and at much lower rates than either Sites 1 or 2 (Appendix C). Tile flow responded slowly to rainfall events from early May until mid July, after which very little to no response was seen following a rainfall event. Peak flows lasted for a few days and then tile flow declined to <100 ml/min until the next rainfall event. Peak flows of 4672 ml/min were measured in early June. Smaller peak flow rates (4400 ml/min) were recorded in June. There was no statistical difference in tile flow rates between treatments.

II) Liquid Manure Application Day

Tile flow was minimal on the day of liquid manure application with only seven of the tiles flowing (Table 3). The average flow rate of the seven tiles was only 0.015 L/min. The application of 56,165 L/ha of liquid manure caused a slight increase in tile flow, averaging

0.020 L/min. Tile flow under all treatments peaked within 45 minutes following manure application and returned to baseline flows within a few hours (Fig. 37).

Table 3. Tile flow rates for treatments prior to liquid manure application, Site 3

Tile Number	Treatment[1]	Flow Rate L/min
1	SA	0.01
2	CI	0.00
3	CO	0.01
4	MI	0.00
5	SA	0.02
6	CI	0.02
7	CO	0.00
8	MI	0.00
9	SA	0.00
10	CO	0.01
11	CI	0.02
12	MI	0.02

[1] CO-Control, MI-Modified Injection, CI-Conventional Injection, SA-Surface Applied

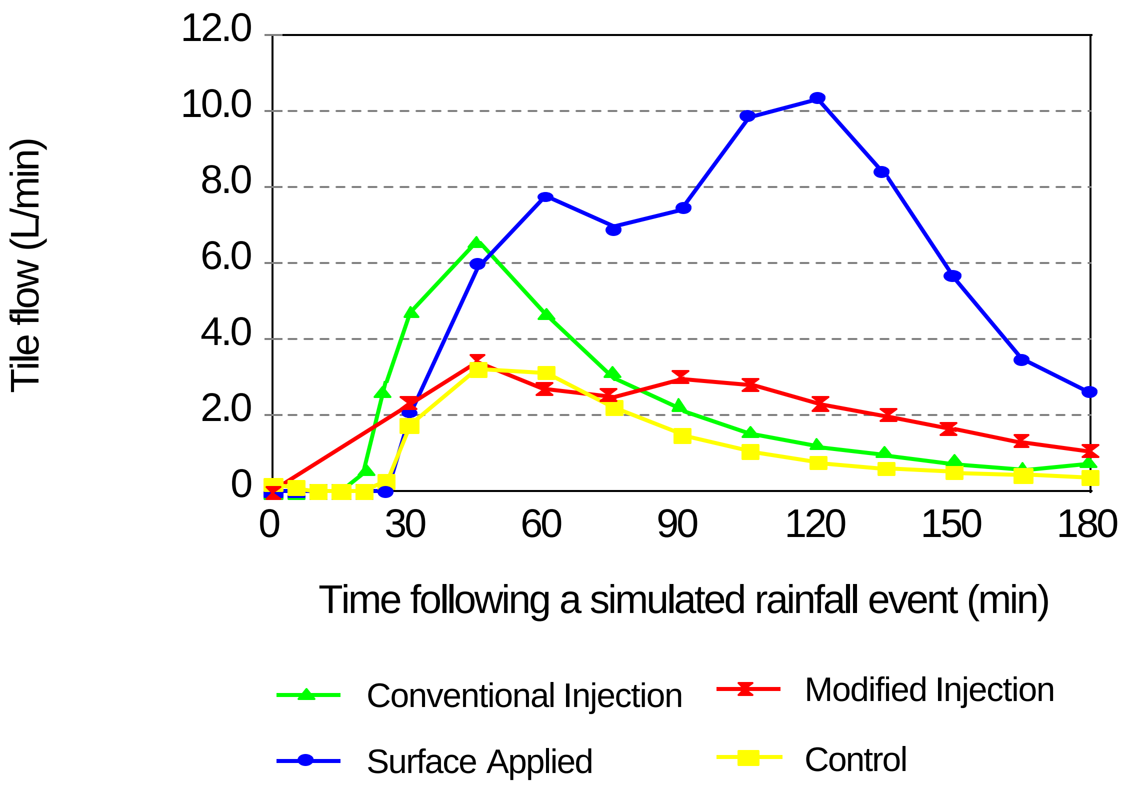

Fig. 39. Tile flow following a simulated rainfall event (1996) for Site 3.

Total three hour flow volumes varied between treatments (Fig. 38). Modified injection had the greatest total flow with 5.44 L while the control tiles had the smallest total flow at 1.13 L. Conventional injection and surface applied flow volumes were in the middle with 3.99 L and 2.49 L respectively. A field average of 0.13% of the applied manure volume came through the tile drains, with the greatest amount (0.2%) from the tiles under modified injection treatments. The surface applied and the conventional injection both had an average of 0.1% of the applied volume of manure reaching the tile drains. Due to the minimal flow rates, there was no significant difference ($p>0.1$) between the treatments.

III) Simulated Rainfall Event

On the day of the simulated rainfall event, a total of 1.9 cm of water was applied to the field using a travelling irrigation gun. There were some problems with the irrigation gun which resulted in some parts of the field receiving slightly larger rates of rainfall water; however there was no statistical difference across the field. Water application resulted in increased flow in all the tiles (Fig. 39). Tiles started to flow between 20 and 30 minutes following the rainfall event and all flows peaked within 120 minutes. Flow rates returned to baseline levels within 12 hours following the simulated rainfall event. The tiles under the surface applied method had the greatest increase in tile flow (11.10 L/min) while the control tiles had the smallest increase in tile flow (3.39 L/min). Flows peaked at 6.59 L/min for conventional injection and at 3.40 L/min for modified injection. The total volumes of water reaching the tile drains as a percentage of applied was relatively small, averaging 3.75% for all treatments (control - 1.5%, modified injection - 2.7%, conventional injection - 3.0% and surface applied - 7.8%). Total flow volumes in the three hour period following the simulated rainfall event was greatest for the surface application but not significantly different ($p>0.1$) than the other treatments (Fig. 40).

4.33) Water Quality

I) Seasonal

Nitrate concentrations were less than water quality standards in May (average 7.50 mg/L) but there was a large increase in nitrate concentrations (22.5 mg/L) in mid June. Concentrations gradually decreased to background levels by the end of July (Appendix D). No increase in nitrate concentrations were detected around the time of manure application. Only a few samples were taken for total phosphorus and soluble phosphorus during the growing season. Total phosphorus concentrations always exceeded water quality standards (avg.-0.6 mg/L). Soluble phosphorus was variable with concentrations ranging from a minimum of 0.05 mg/L to a maximum of 0.4 mg/L.

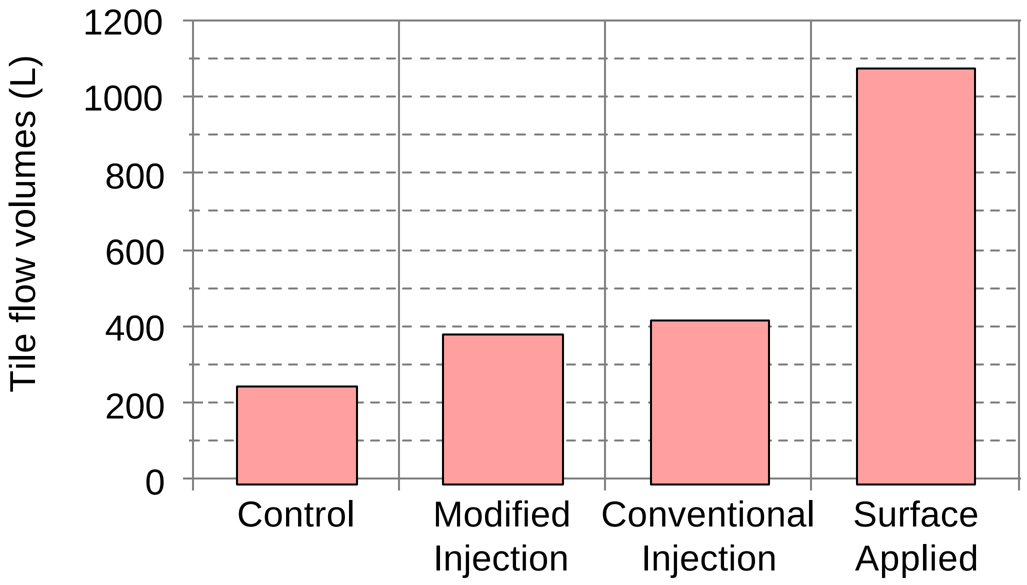

Fig. 40. Total tile flow volumes for the 3hr period following a simulated rainfall event (1996) for Site 3.

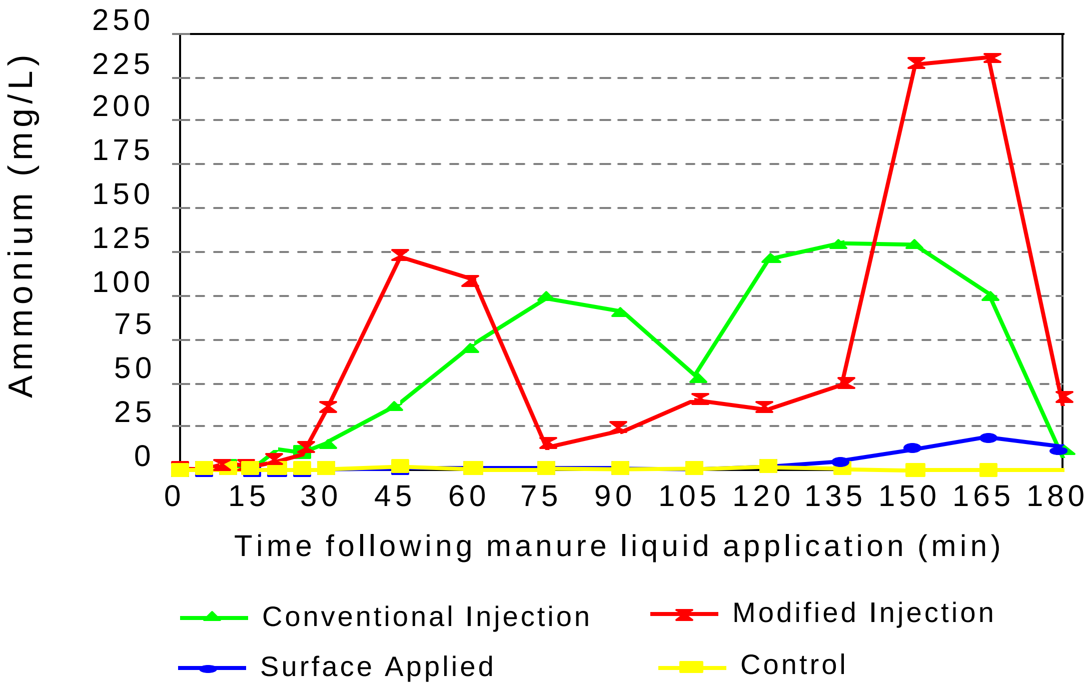

Fig. 41. Ammonium concentrations in the tile water following liquid manure application (1996) for Site 3.

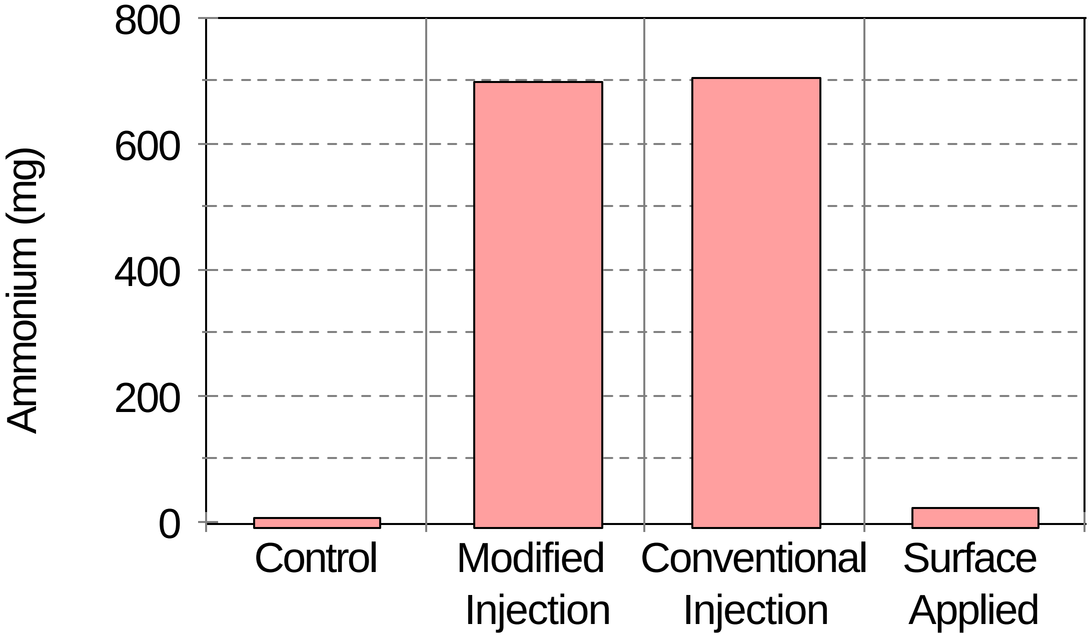

Fig. 42. Ammonium loadings in the tile water for the 3hr period following liquid manure application (1996) for Site 3.

II) Liquid Manure Application

Levels of ammonium, phosphorus, bromide and bacteria increased within three hours following manure application from all the treatments (data available in COESA Rep.# RES/MON-009/97 - Agriculture and Agri-Food Canada, 1997).

Ammonium concentrations exceeded aquatic water quality standards (1.37-2.2 mg/L) within 20 minutes following liquid manure application under the injection methods, but did not increase until 135 minutes under the surface application method (Fig. 41). The greatest concentration increases were seen with the modified injection, with individual tiles peaking at 230 mg/L. Much lower concentrations were detected under the conventional injection (130 mg/L) and the surface applied (22 mg/L) treatments. The concentrations in the control tile water did not change. Ammonium concentrations decreased to background levels within 12 hours following liquid manure application.

Ammonium loadings were calculated for a three hour period following manure application (Fig. 42). Total loadings of ammonium were greatest for conventional injection (0.702 kg), followed by modified injection (0.696 kg) and surface applied methods (0.018 kg). There was a small amount of ammonium present in the control tile (0.002 kg). There was no significant difference ($p>0.1$) detected between treatments due to great variability and minimal tile flow.

Bacteria tracer (E.coli) levels in the tile water exceeded drinking water quality standards (0 counts/100ml) within 30 minutes following manure application and peaked within 135 minutes for all treatments (Fig. 43). Bacteria tracer levels increased from 0 counts/ml for all treatments to 1.18×10^5 counts/ml for conventional injection, 1.22×10^5 counts/ml for modified injection and 2.5×10^4 counts/ml for surface applied. Bacteria tracer loadings calculated for a three hour period following manure application were not significantly difference between treatments, although the tiles under injection methods had greater bacteria loadings than the surface applied treatment (Fig. 44).

Liquid manure application resulted in greater phosphorus concentrations under all application methods. Total phosphorus concentration was greatest for the modified injection method, peaking at 36.4 mg/L (Fig. 45). Conventional injection and surface applied treatments had smaller concentrations peaking at 7.9 mg/L and 3.8 mg/L, respectively. Soluble phosphorus concentrations were greatest under modified injection (0.2 mg/L) followed by conventional injection and surface applied treatments (0.1 mg/L each). Soluble phosphorus loadings for a three hour period following manure application are shown in Figure 46.

Bromide was found in the tile drains within 30 minutes following manure application (Fig. 47). Bromide concentrations peaked within 150 minutes of application for conventional injection and surface applied, but did not peak in the modified injection until

180 minutes. Conventional injection had the greatest concentration of bromide (1.9 mg/L) while modified injection and surface applied treatments were less, at 0.76 mg/L and 0.42 mg/L, respectively. The percentage of bromide found in the tile drain water relative to the total amount of bromide applied was extremely small, less than 0.5% (conventional injection - 0.01%, modified injection - 0.003%, surface applied - 0.001%). Total bromide loadings were higher for the conventional injection method, but not statistically ($p>0.1$) different (Fig. 48).

Within 12 hours following manure application, ammonium, bacteria and phosphorus levels had decreased to background levels. Bromide was still detectable in some of the tiles, but at very low concentrations (0.01 mg/L).

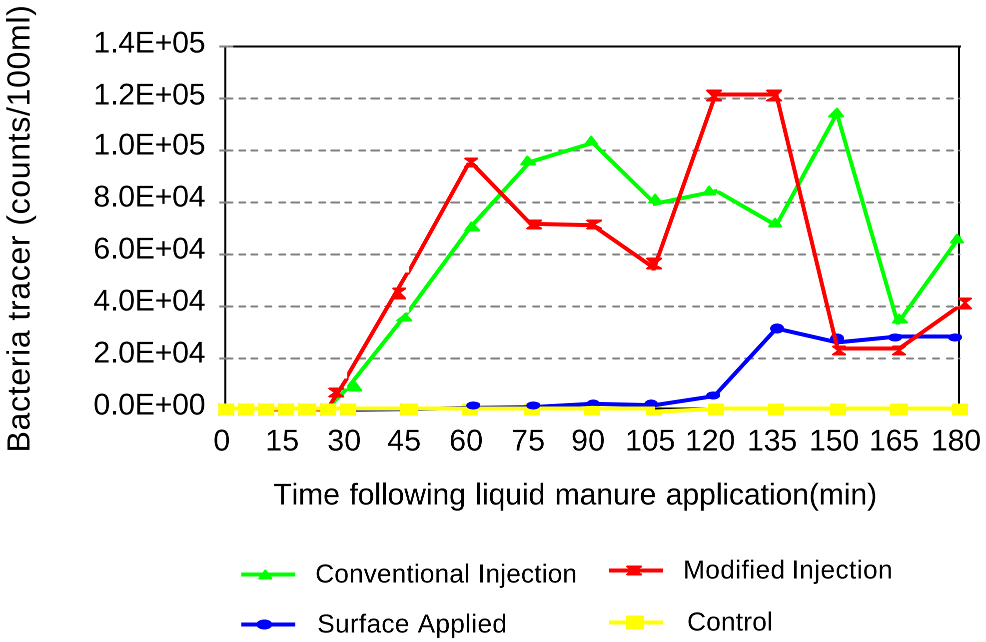

Fig. 43. Bacteria concentrations in the tile water following liquid manure application (1996) for Site 3.

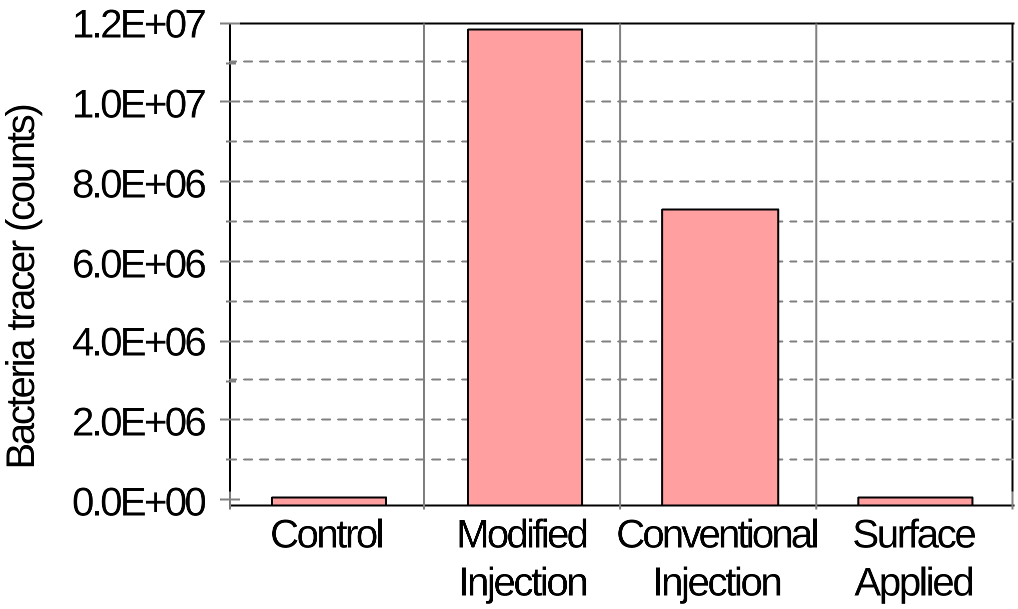

Fig. 44. Bacteria tracer loadings in the tile water for the 3hr period following liquid manure application (1996) for Site 3.

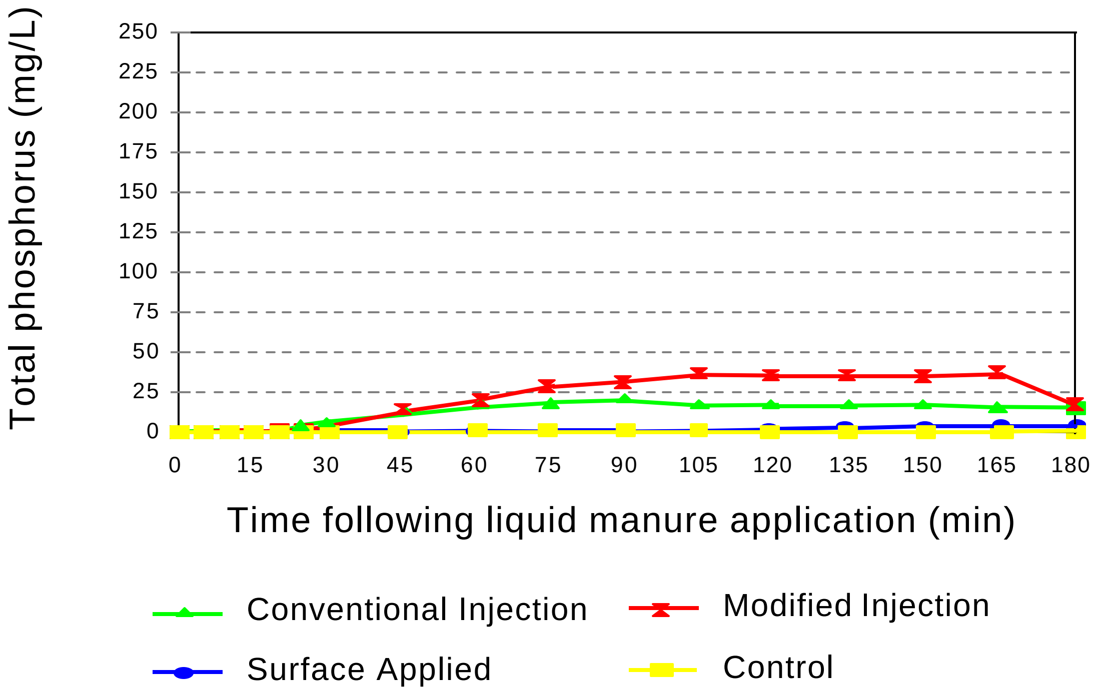

Fig. 45. Total phosphorus concentrations in the tile water following liquid manure application (1996) for Site 3.

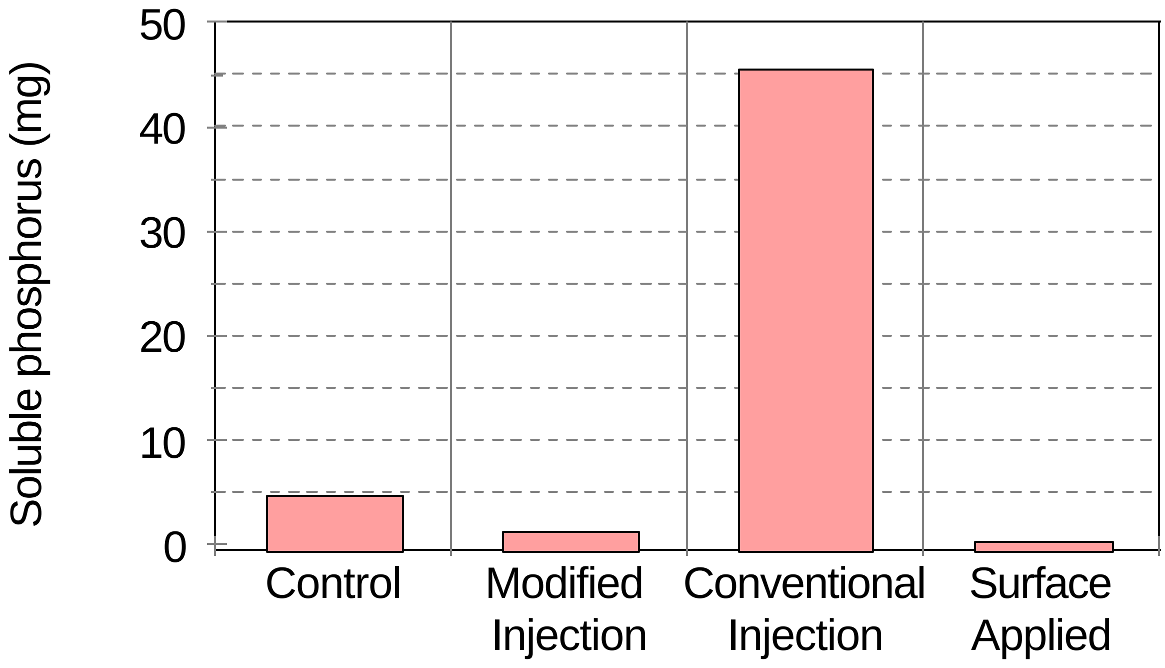

Fig. 46. Soluble phosphorus loadings in the tile water for the 3hr period following liquid manure application (1996) for Site 3.

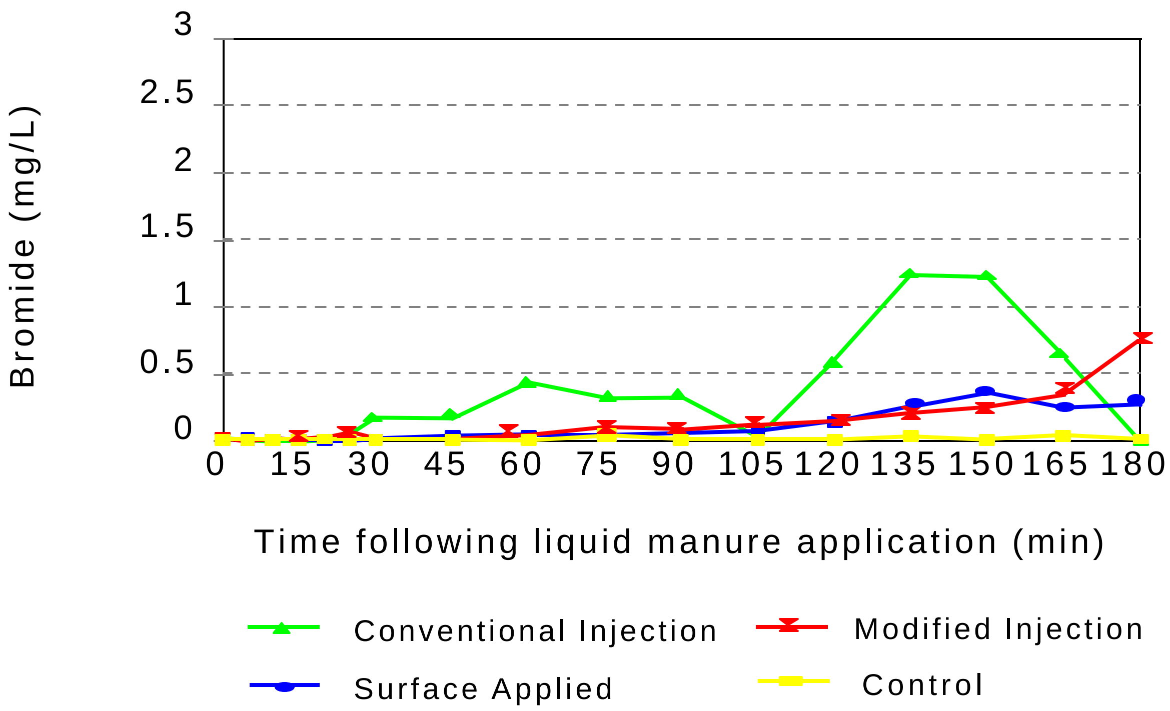

Fig. 47. Bromide concentrations in the tile water following liquid manure application (1996) for Site 3.

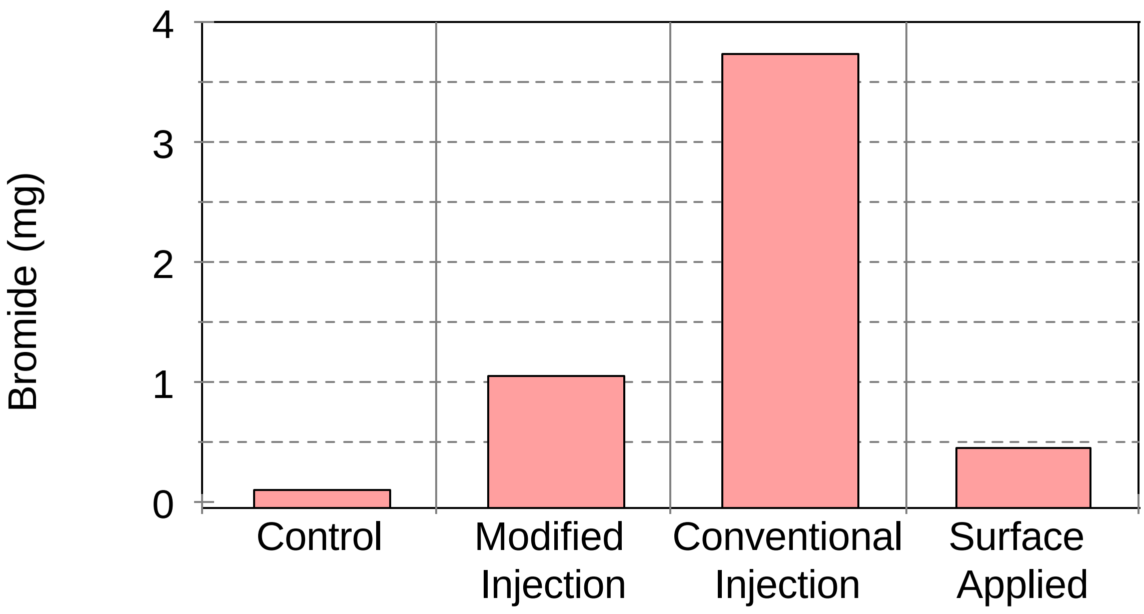

Fig. 48. Bromide loadings in the tile water for the 3hr period following liquid manure application (1996) for Site 3.

III) Simulated Rainfall Event

All treatments had increased levels of ammonium, phosphorus, bacteria tracer and bromide concentrations in the tile water within 30 minutes following the start of the simulated rainfall event, and nutrient concentrations peaked within 60 minutes (COESA Rep. # RES/MON-009/97 - Agriculture and Agri-Food Canada, 1997).

Ammonium concentrations were less overall on the day of the simulated rainfall event than on the day of manure application. Concentrations from individual tiles only reached a maximum of 9.7 mg/L (Fig. 49). Conventional injection had the greatest concentrations followed by modified injection, surface applied and the control tiles. All concentrations peaked within 30 minutes, but receded to background levels within 3 hours following the simulated rainfall event. Ammonium loadings during this period ranged from a minimum of 0.7 kg in the control tiles to a maximum of 2.8 kg in the surface applied tiles (Fig. 50). The modified injection and the conventional injection were similar, with values of 1.4 kg and 1.9 kg, respectively. There was no statistical significance (90%) due to the great variations in tile flow.

Bacteria tracer concentration was monitored for three hours following the simulated rainfall (Fig. 51). The surface applied method had the greatest bacteria concentrations with individual tiles peaking at 1.26 x 10^5 counts/100ml. Both injection methods were much smaller, peaking at 2.98 x 10^4 counts/100 ml for modified injection and 1.13 x 10^4 counts/100 ml for conventional injection. A small amount of bacteria tracer was detected under the control tiles (<1.0x 10^3 counts/100ml). All treatments peaked within the first 45 minutes following the start of the simulated rainfall event, and receded to baseline levels within 12 hours. The surface applied treatment had statistically greater amounts of bacteria tracer loadings than either of the injection methods ($p>0.1$). In addition, the injection methods were not significantly greater than the control tiles (Fig. 52).

Total phosphorus concentrations exceeded water quality standards within 45 minutes following the simulated rainfall event and declined to background levels within 12 hours (Fig. 53). The greatest concentration was found under the conventional injection method, peaking at 16.1 mg/L. Modified injection had slightly smaller (13.6 mg/L) concentrations, and surface applied had the smallest concentrations (7.4 mg/L). Soluble phosphorus concentrations also increased, being greatest under the modified injection method (1.5 mg/L) followed by surface applied (0.06 mg/L) and conventional injection(0.3 mg/L). Surface applied had significantly greater soluble phosphorus loadings than the control tiles, but was not statistically different from either of the injection methods at a 90% confidence level (Fig. 54).

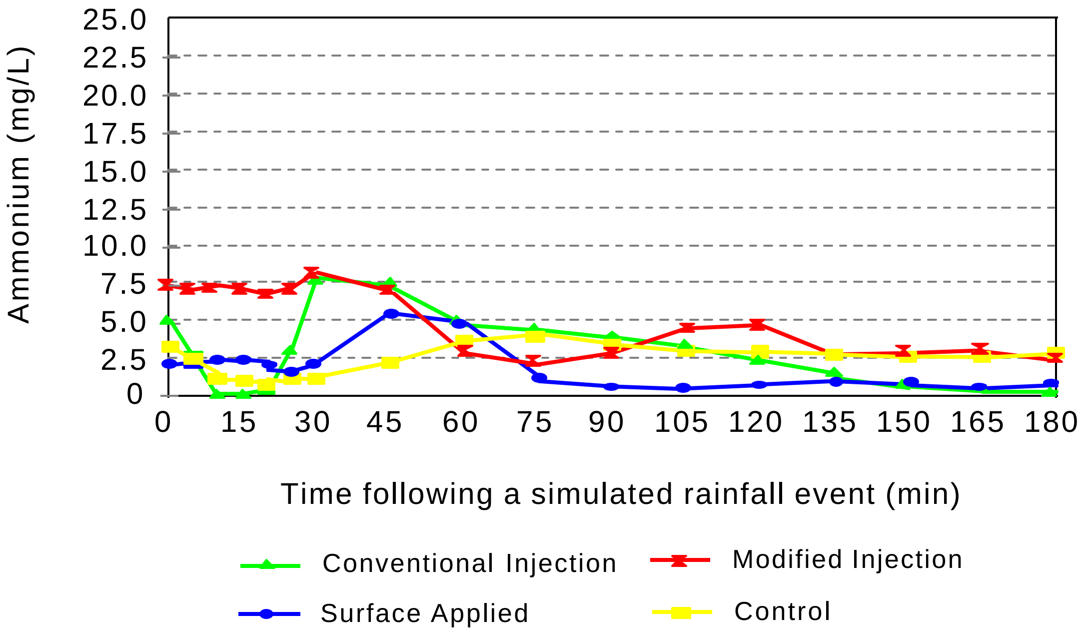

Fig. 49. Ammonium concentrations in the tile water following a simulated rainfall event (1996) for Site 3.

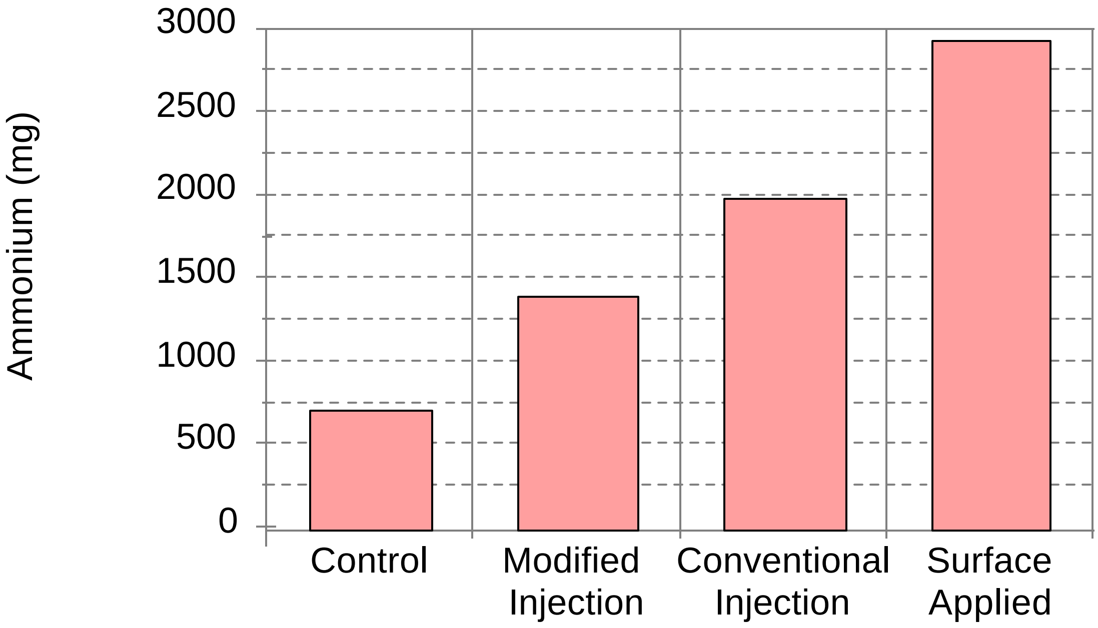

Fig. 50. Ammonium loadings in the tile water for the 3hr period following a simulated rainfall event (1996) for Site 3.

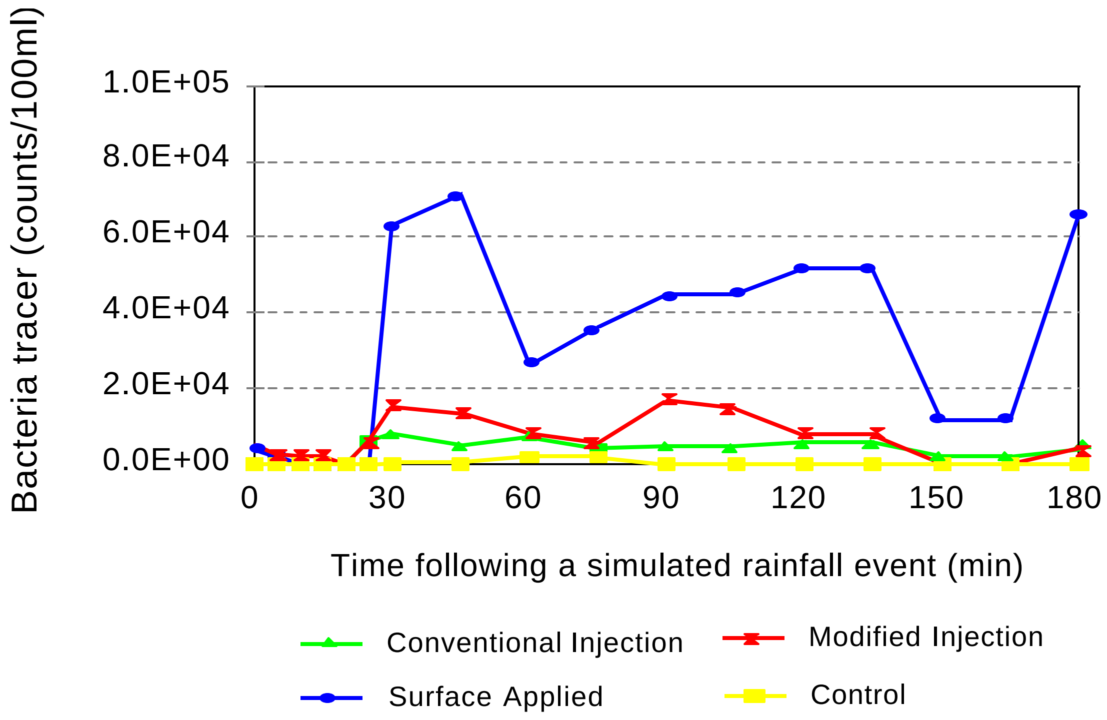

Fig. 51. Bacteria tracer counts in the tile water following a simulated rainfall event (1996) for Site 3.

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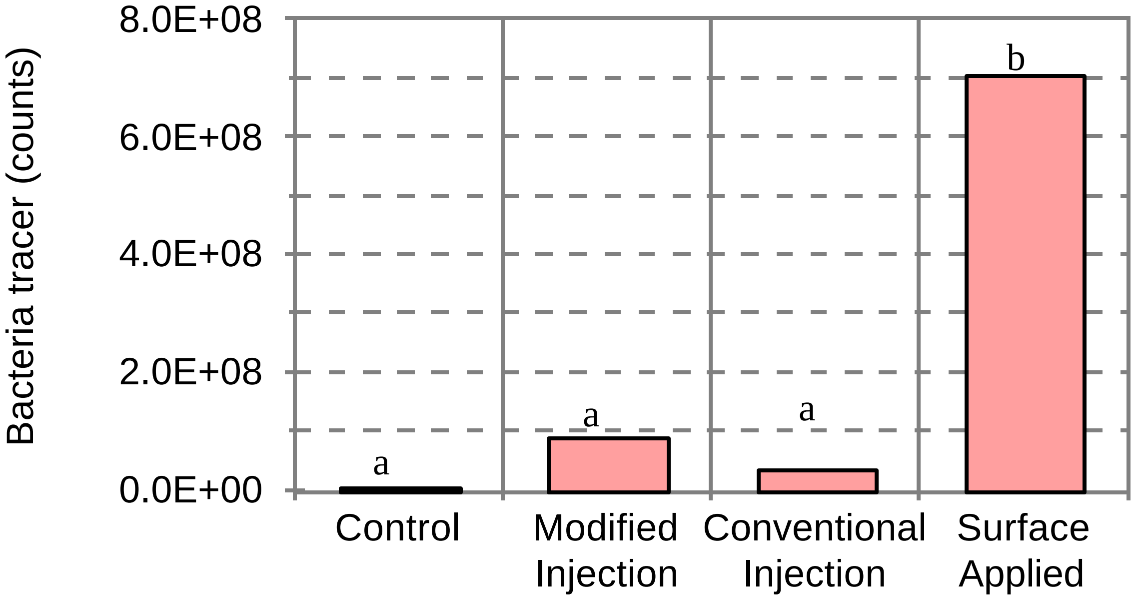

Fig. 52. Bacteria tracer loadings in the tile water for the 3hr period following a simulated rainfall event (1996) for Site 3.

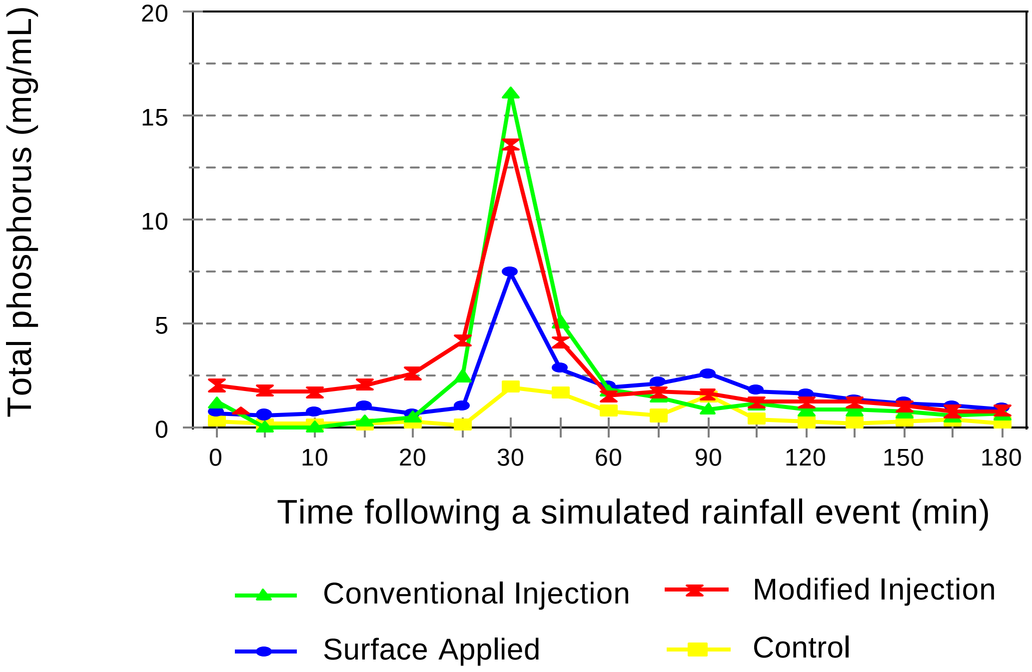

Fig. 53. Total phosphorus concentrations in the tile water following a simulated rainfall event (1996) for Site 3.

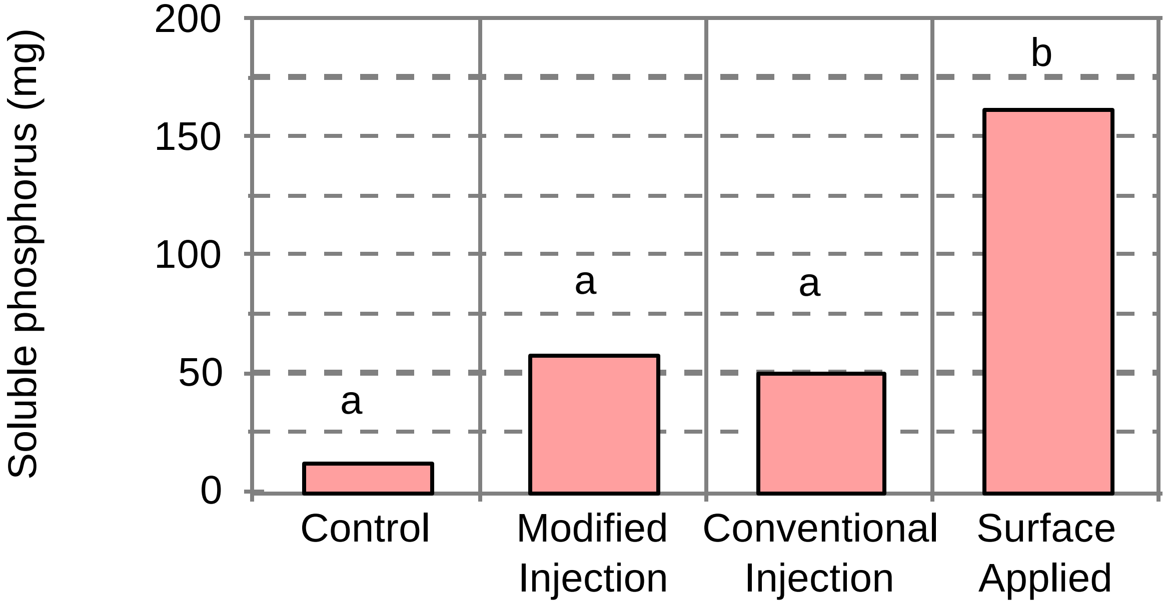

Fig. 54. Soluble phosphorus loadings in the tile water for the 3hr period following a simulated rainfall event (1996) for Site 3.

Bromide was detected in the tile water for all manure treatments, and concentrations peaked within 75 minutes from the start of the simulated rainfall(Fig. 55). The greatest concentration was detected under conventional injection (0.60 mg/L), followed by modified injection (0.52 mg/L) and surface applied (0.47mg/L). Bromide loadings from the surface applied treatment, in the three hour period following the rainfall event was significantly greater than the injection methods and control tiles (Fig. 56). Both injection methods were not significantly different from the control tiles. The amount of applied bromide being flushed into the tile drains was much greater than on the day of manure application, with the greatest amount being measured under the surface applied treatment (1.3%), while conventional injection and modified injection were less, at 0.6% and 0.4%, respectively.

4.34) Agronomic Monitoring

Plant populations at harvest between control, surface applied and conventional injection manure treatments were within 2% and did not differ significantly (Table 12). The modified injection method however, suffered a 7% reduction in final plant population compared to the control plots. This reduction was largely due to plant damage at the time of manure application. Excessive mechanical movement of the soil caused seedling damage. Plant tissue analysis was the first indication that the soil fertility level could result in a reduction in crop yield. All treatments were below critical concentrations for N, P and K.

Further complications arose as wet soil conditions in the fall prevented timely harvest. The crop was harvested in January after freeze-up, under snowy conditions, that contributed to lodging of greater than 50% across the field. Grain moisture content at this time (27.6%) was not significantly different between treatments. Grain yield averaged 6.653 t/ha and was not significantly different ($p>0.1$) among treatments. The crop showed a significant response to the inorganic and organic fertilizer as check plots averaged 2.364 t/ha. Surface applied and conventional injection plots were similar in yield (-2% and +1%, respectively) to the control plots (6.768 t/ha). The modified injection method resulted in a 6% yield reduction from the control, similar to the reduction recorded in plant population.

June soil test results indicated adequate P and K, however the residual nitrogen level was low at approximately 50 kg N/ha. (Appendix E). The manure had a greater nitrogen content at Site 3 compared to Site 2, which required lowering the rate of manure applied however, the rate of nitrogen applied was 168 kg N/ha. Soil nitrogen sampling conducted in September indicated inorganic and organic sources of nitrogen were depleted to below pretreatment levels. The similar crop response to inorganic and organic fertilizer as shown with the check plot yields would suggest any growth limitations were independent of treatments.

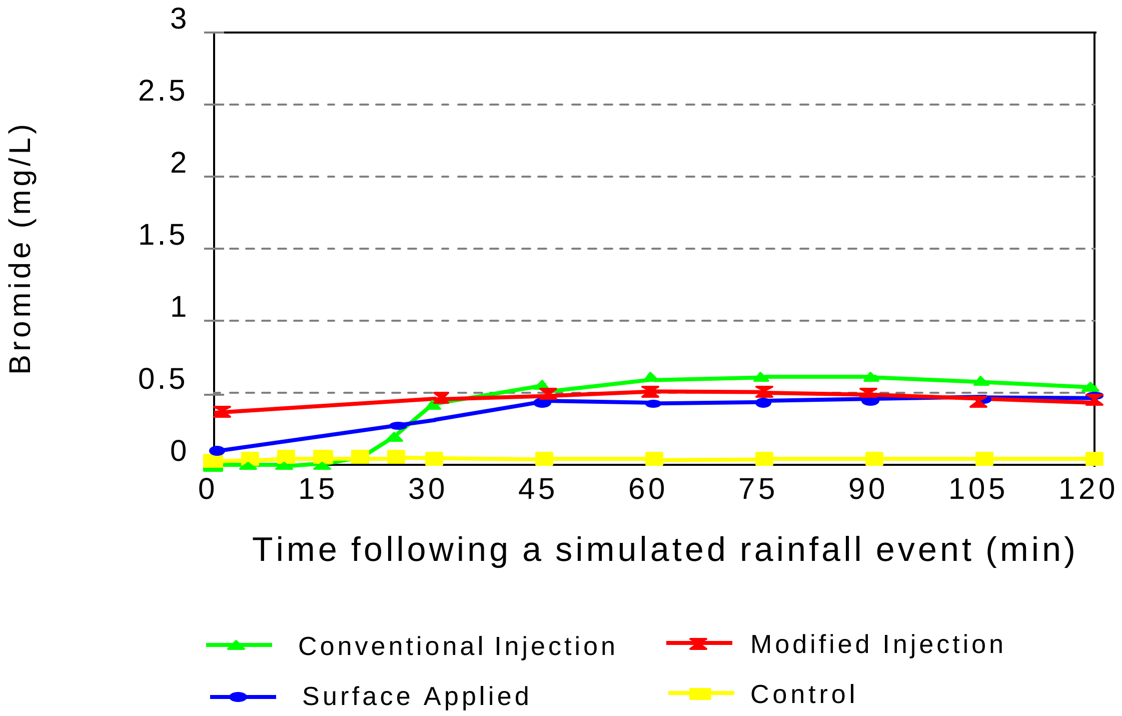

Fig. 55. Bromide concentrations in the tile water following a simulated rainfall event (1996) for Site 3.

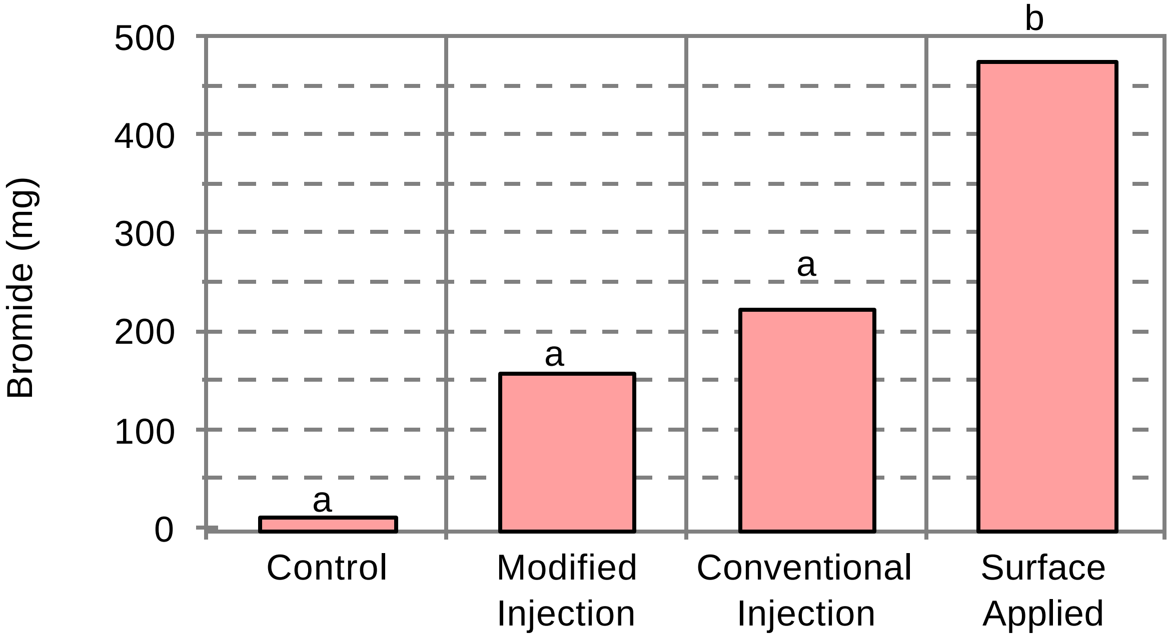

Fig. 56. Bromide loadings in the tile water for the 3hr period following a simulated rainfall event (1996) for Site 3.

4.4) Computer Modelling

At Site 1, 47% of the modelled daily tile flows were not significantly different ($p>0.05$) from the measured flows. The model (DRAINMOD 4.0) underestimated the daily tile flow 20% of the time, and over estimated it 33% of the time during the growing season. The average measured and modelled tile flows during simulation and the statistical results are shown in Appendix B. The model did not accurately reflect the initiation of flow after a rainfall event even though monthly total volumes of flow were accurate. Figure 57 shows specific rainfall events where the measured tile flow increased quickly after the initiation of a rainfall event. The modelled tile flow delayed and underestimated the initial flow response. While the monthly volume of tile flow was accurate, the response time of the model did not accurately reflect differences in flow in the days following an event. Since an immediate response of tile flow after an event is often produced by macropore flow, the model may not include an algorithm to simulate that process. A further source of error in the flow simulations may also exist due to the inability of the model to vary soil conditions such as hydraulic conductivity with time.

At site 2, 36% of the modelled daily tile flows were not significantly different from the measured flows. The model underestimated the daily tile flow 6% of the time, and overestimated it 58% of the time during the growing season. Differences may have existed due to the temporal variability and inconsistency of the measurements of hydraulic conductivity. The lower horizons at some parts of the field were too stony or too gravelly to get accurate hydraulic conductivity measurements. Also, since no quantitative data were available for surface runoff events or lateral hydraulic conductivity, the estimate of lateral hydraulic conductivity may not have been accurate. Comparing predicted data to the actual tile flow data set was difficult because of gaps in the data.

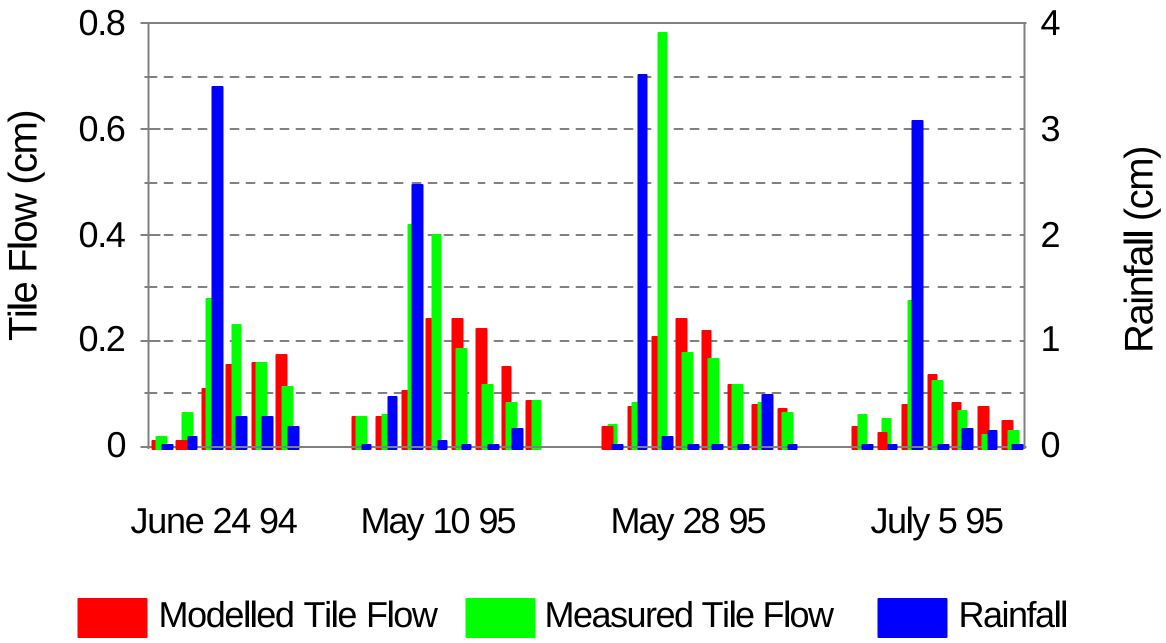

Fig. 57. Modelled tile drain flow vs measured tile drain flow following rainfall events at Site 1.

4.50) Energy Requirements

Machine draft for all treatment configurations was the same order of magnitude as draft for the same machines obtained on barley and alfalfa stubble in an earlier experiment (McLaughlin et al. 1997). Draft data for both types of injection were always much higher than for surface spread for all locations and years (Table 4). This difference is expected since the draft of the surface spread is simply the rolling resistance of the tanker, while draft for the injection is rolling resistance of the tanker plus the resistance of the soil-engaging injection tools. The modified injection configuration had more draft than the conventional injection for all locations and years except at Site 1, 1995 where it was not significantly different ($p>0.05$). The modified injection configuration had extra soil-engaging tools for pre-tillage which created extra draft.

Table 4. Mean tanker draft in kN for three different application methods and five site/year combinations. (The data has been adjusted to a full tanker load).

Location and Year	Site 1 1994	Site 1 1995	Site 2 1995	Site 2 1996	Site 3 1996
Direction	Down Slope	Down Slope	Up Slope	Up Slope	Down Slope
Modified Injection	11.79 a	11.17 a	10.10 a	16.46 a	11.31 a
Conventional Injection	7.88 b	11.37 a	8.60 b	12.77 b	5.06 b
Surface	4.18 c	2.77 b	5.02 c	6.29 c	2.54 c

Means in the same column and followed by the same letter do not differ significantly ($p>0.05$) according to Duncan’s Multiple Range Test.

At Site 3, the soil had a higher clay content, and the surface was dry and hard. Test runs resulted in large clods of soil being thrown onto the corn causing considerable damage to the crop. The injector tool bar was raised slightly (3-5 cm) in an effort to reduce the crop damage. This change resulted in the injector teeth being very shallow for the conventional injection configuration. The shallow depth of the injectors is shown in the draft data where conventional injection was less than half of modified injection. In other locations and years, conventional injection draft ranges from 66% to 102% (Site 1, 1994 and 1995 respectively) of the modified injection draft.

Manure was applied driving up slope at Site 2, and driving down slope at Sites 1 and 3. The Site 2 draft data is much higher than the other two locations for 1996, but not for 1995. The differences in soil conditions masked differences due to direction of application. Draft data could be corrected for slope; however, accurate slopes were not taken to make this correction.

Fuel consumption, expressed both as litres per hour (Table 5) and litres per hectare (Table 6), always followed the same trend as draft, within a location and year. The ranking of the three application methods was always the same for draft and fuel consumption. This similarity is expected since the same engine speed and gear were used for all three methods within a location and year, and for a given engine speed and gear, fuel consumption is closely related to draft. The same ranking helps establish confidence in the data.

Table 5. Mean tractor fuel consumption (litres per hour) for three different application methods at the three sites and years. (The data has been adjusted to a full tanker load).

Location and Year	Site 1 1994	Site 1 1995	Site 2 1995	Site 2 1996	Site 3 1996
Direction	Down Slope	Down Slope	Up Slope	Up Slope	Down Slope
Modified Injection	11.51 a	11.97 a	11.27 a	13.40 a	10.51 a
Conventional Injection	10.29 b	12.01 a	10.60 a b	12.42 b	8.33 b
Surface	9.09 c	8.36 b	10.25 b	10.45 c	7.80 b
Means in the same column and followed by the same letter do not differ significantly (p>0.05) according to Duncan’s Multiple Range Test.					

Table 6. Tractor fuel consumption (litres per hectare) for three different application methods at the three sites and years. (The data has been adjusted to a full tanker load).

Location and Year	Site 1 1994	Site 1 1995	Site 2 1995	Site 2 1996	Site 3 1996
Direction	Down Slope	Down Slope	Up Slope	Up Slope	Down Slope
Modified Inject	7.58 a	6.03 a	8.17 a	8.99 a	6.20 a
Conventional Inject	6.68 b	6.09 a	7.64 a b	8.28 b	4.78 b
Surface	5.91 c	4.29 b	7.44 b	6.79 c	4.46 b
Means in the same column and followed by the same letter do not differ significantly according to Duncan's Multiple Range Test (p>0.05).					

The ranking of location and year within an application method were sometimes different for tanker draft and tractor fuel consumption. This difference was mainly due to different tractor engine speed and gear ratios used to obtain the different target application rates, based on soil and manure nitrogen tests, among locations and years. The different gear ratios and engine speeds affect engine load and efficiency, and therefore fuel consumption even for constant draft.

The tractor data clearly shows the extra power and energy required for the modified injection configuration over the conventional injection, however, the overall difference in fuel consumption is small (10%). McLaughlin et al. (1997) found that the modified injection configuration with a leading coulter and 50 mm cultivator spike followed by 50 mm wide injectors had a lower draft requirement than a tanker with conventional 570 mm wide injectors. The modified injection configuration is considered practical from an energy perspective.

5.0) DISCUSSION

Field scale studies were conducted in the Mixedwood plain ecozone to evaluate crop yield and environmental impacts of no-till corn production using liquid hog manure as the primary source of fertilizer nitrogen. Three imperfectly drained soils (Site 1-Embro, Site 2 - Brisbane, Site 3 - Perth) were studied with contrasting textures (silt loam, sandy loam, clay loam). The clay and organic matter contents of the plow layer of the three study sites (1 to 3) were 17%, 11%, 34% clay and 4.9%, 4.4%, 3.1% organic matter respectively. The soils represent the range of soils used for crop and hog production in this ecozone. Each of the study sites had a history of at least 5 years of no-till crop production and had been systematically tile drained for at least 10 years. Field data was collected over 3 growing seasons (1994-1996). Two years of data were gathered from Sites 1, 2 and 1 year from Site 3.

Climatic data (precipitation, temperature) for the study period (data available in COESA Rep.# RES/MON-009/97-Agriculture and Agri-Food Canada, 1997) relative to long term (30 yr) normals for the Environment Canada London airport station are shown in Table 7. In 1994, the rainfall and temperature data from the Site 1 location and an Agriculture and Agri-food station 20 km away indicated no moisture or temperature limitations to crop growth. However, a 50-mm rainfall within 24 hours following manure application prevented the planned rainfall simulation. Field studies were conducted at Sites 1 and 2 in 1995. Growing season temperatures were generally warmer than long term norms (June and August averaged 2°C higher) however precipitation was also above the normals for May through August by 30%, 109%, 18%, and 43%, respectively. Weather variations did not create visible crop growth stress conditions in 1995 or 1996. In 1996, Sites 2 and 3 had temperature mean values that were about one degree above or below the long term mean for the June to August period. Site 2 had mean precipitation values that were 135%, 79%, 61%, and 54% above the mean for the months May to August respectively. A cold and wet September at Site 3 however delayed crop maturity and led to delaying harvest until the ground was frozen in January.

Tile flow at the three study sites varied in both rate and response time to rainfall. The tile drains at Site 1 flowed for most of the growing season. Sites 2 and 3 flowed continuously in the spring as snow melt and excess soil moisture was drained from the soil, then flowed only in response to rainfall events during the growing season. None of the sites flowed in the mid July to August time period of moisture deficits. The mean monthly flows of the study sites illustrate the large volumes of tile water from Sites 1 and 2 relative to Site 3 (Table 8). Site 3 had usually less than half the total volume of tile water than either Sites 1 and 2. Site 1 had greater volumes of tile flow in 1995 over Site 2 in May, but as soil moisture decreased the total tile flow became equal. The larger volumes from the tiles at Site 1 in early spring suggest that ground water flow from outside the study area may have been contributing to flow. Table 9 shows monthly peak flow rates for the study sites. Monthly peak flows were variable at all sites but generally Site 2 had higher peak flows. Peak flows at Site 3 were usually half the volume of the first and second sites. Tile flow response rates to rainfall events were rapid in the early part of the growing season when soil moisture levels were greater. As the soil moisture at each site declined in the July to August period, the tile drains no longer responded to rainfall events at any of the study sites. This observation was most evident at Site 2 where the sand textured soil had the smallest moisture holding capacity.

Table 7: Climate records for London (1950-1980) and study sites for the extended growing season

Location and Year		Growing Season Precipitation (mm)							
		April	May	June	July	August	September	October	
London (30 yr.)		69.5	73.6	81.9	76.7	89.5	86.2	73.8	
Site 1 - 1994			97.3	105.6	92.2	27.7	27.8	17.2	
Site 1 - 1995		98.2	85.0	57.7	28.5	73.6	25.3	125.6	
Site 2 - 1995			95.4	170.9	90.4	128.4	28.2	163.2	
Site 2 - 1996		163.3	131.5	132.2	118.2	33.3	283.7	123.0	
Site 3 - 1996			81.4	92.1	70.2	28.1	145.6	57.0	
		Growing Season Temperature (ºC)							Corn Heat Units
London (30 yr.)	Mean	6.2	12.6	17.7	20.3	19.3	18.3	9.1	
	Avg daily max	11.7	18.7	23.9	26.4	25.2	20.9	14.2	
	Avg daily min	0.7	6.4	11.6	14.2	13.3	9.6	3.9	
Site 1- 1994	Mean		12.1	18.6	19.9	17.7	15.0	9.6	2729
	Avg daily max		17.3	24.5	25.4	23.2	21.4	15.5	
	Avg daily min		6.0	12.7	14.7	13.9	9.2	4.7	
Site 1- 1995	Mean	3.4	12.3	20.0	20.5	21.0	13.8	10.1	3017
	Avg daily max	8.5	18.1	25.9	25.9	26.7	20.4	15.0	
	Avg daily min	-1.0	6.9	14.4	15.2	15.8	7.2	5.4	
Site 2 - 1995	Mean		12.9	20.0	20.5	21.0	13.9	9.9	3022
	Avg daily max		18.3	25.9	25.9	26.8	20.8	15.7	
	Avg daily min		7.3	14.4	15.2	15.7	7.1	4.8	
Site 2 - 1996	Mean	4.2	12.1	17.8	19.2	19.5	15.2	9.1	2851
	Avg daily max	9.9	17.8	22.6	25.2	26.2	20.6	15.0	
	Avg daily min	-0.8	6.0	13.0	12.6	12.5	10.4	3.7	
Site 3 - 1996	Mean		11.8	18.9	19.2	19.9	16.0	10.1	2954
	Avg daily max		17.4	23.7	25.1	24.4	23.4	17.5	
	Avg daily min		5.9	14.2	13.3	15.4	10.2	4.2	

Table 8. Mean monthly flows (L/month) for the three study sites.

Site/Year	May	June	July	August	September	October
1- 1994	61.41	26.06	14.80	1.59	0.08	0.09
1- 1995	60.44	20.84	16.59	2.91	0.07	20.03
2- 1995	20.42	26.98	7.97	0.18	0.00	1.22
2- 1996	60.84	36.83	0.15	0.00	33.76	0.00
3- 1996	15.83	13.38	4.16	N/A	N/A	N/A

Table 9. Mean monthly peak flow rates (L/month) for the three study sites.

Site-Year	May	June	July	August	September	October
1- 1994	3.67	4.27	3.10	0.47	0.01	0.02
1- 1995	11.66	1.93	3.69	1.17	3	3.12
2- 1995	6.98	6.76	5.89	0.09	0	1.17
2- 1996	16.98	13.34	0.03	0	18.60	0
3- 1996	4.67	4.46	2.75	N/A	N/A	N/A

Background nitrate levels in the tile water were greatest (about 25 mg/L) at Site 2 and least (about 8 mg/L) at Site 1. The nitrate levels of tile flow at planting time at Site 3 were about 20 mg/L but declined to about 7.0 mg/L by the time of manure application. Liquid manure application did not affect nitrate concentration of the tile water since the manure nitrogen was predominantly in the ammonium form. Any increase in nitrate levels of tile water associated with manure application did not occur for 1 to 2 weeks following manure application.

A no-till corn crop was planted in late May at each of the study sites as soil moisture allowed. Up to 36 kg N/ha of starter fertilizer was applied across the treatment according to farm co-operator's preference with the control plots also receiving recommended rates of inorganic nitrogen. The sand textured soil at Site 2 was usually ready for planting earliest. Sites 1 and 3 which had higher clay contents, and high residue levels associated with no-till, were slower to reach soil moisture levels appropriate for planting. In about the third week of

June, soil and manure samples obtained from each site for nutrient testing indicated that the balance of the crop nitrogen needs could be obtained with a liquid manure application rate which averaged around 67,400 L/ha for the three sites.

The liquid hog manure was applied to the field plots by surface application and 2 injection techniques, conventional injection and injection modified by slight tillage in front of the injector. Control plots fertilized with inorganic commercial fertilizers at recommended soil test rates and check plots with no fertilizer or manure added, provided reference information. The manure injection process created problems at Site 3 by tossing large clods onto the corn seedlings. Surviving plant populations at this site were significantly lower (6%) for the modified injection application compared to the control treatment. The clay content and elevated moisture level at Site 3 were particularly difficult since the manure tended to pond in the injector slot where the large soil clods had been moved by the injectors to the corn rows. It was apparent that the injection equipment used in this study would require modification or be used at lower moisture conditions for successful application to high clay (>30%) soils.

Tile flow rates prior to manure application varied among sites. Site 1 flows were the greatest (about 1.30 L/min) and not significantly different between tiles, while flow rates at Sites 2 and 3 were both smaller (0.50 and <0.015 L/min respectively) and not uniform between the 12 tiles monitored. The liquid manure application resulted in a slight increase in tile water flow volumes within 30 minutes of application where tiles were initially running. At Site 2 the liquid manure application caused some tiles to start flowing at low (0.06 L/min) rates. In all cases, flow rate increases resulting from manure application returned to baseline level within 3 hours following application. The volume of applied manure reaching tile drains was <3%(Table 10). There was no significant difference between manure application treatments and tile flow rates following manure application.

Application of liquid manure at all sites when the tile drains were flowing usually resulted in water quality impairments to tile drainage water for 2 to 3 hrs following manure application. A visible change of colour in tile water resulting from contamination by the manure occurred in 7 to 30 minutes from the time of application. While the amount of manure reaching the tile drains was relatively small compared to the amount applied (Table 10), water quality standards for bacteria, phosphorus and ammonium were always exceeded for several hours, before returning to background levels. Bacteria and chemical tracers added to the liquid manure were detected in the tile water samples. The presence of these tracers in the tile water provided evidence that the liquid manure addition to the field sites was the primary source of tile water contamination observed.

A simulated rainfall event was conducted the day following manure application to determine its impacts on tile water quality. Approximately 2 to 3 cm of rainfall was applied over approximately a 20 minute period. Site 1 tile flow rates peaked within 70 minutes after rainfall with flows increasing by about 20 L/min. Tile flows did not return to baseline levels for several days. The total volume of rainwater reaching the tile drains was about 10% with no significant differences between treatments (Table 11). Site 2 tile flow rates peaked about 135 min after rainfall with flow rates increasing to about 5 L/min in 1995 when the soils were dry. In 1996 when soil moisture levels were greater at the time of simulated rainfall, the tile flow rates peaked about 90 min after rainfall with peak flow rates increasing by about 20 L/min. The amount of rainfall reaching the tile drains was about 1% in the dry year (1995) and about 13% in 1996. Site 3 tile flow rates peaked about 120 min after rainfall began and returned to base levels within 12 hours. Peak flow rates increased by about 7 L/min while about 4% of the rainwater reached the tile drains.

Simulated rainfall resulted in increased tile water concentrations of ammonium, phosphorus, bacteria tracer, and bromide for all treatments within 30 min of the start of the rainfall, and peaked within 60 minutes. Ammonium, phosphorus and bacteria concentrations generally exceeded water quality standards but did not reach concentrations as high as found following manure application. Loadings however were significantly greater due to the larger volumes of water coming through the tile drains. While there were no significant differences between application methods at sites 1 and 2, the manure injection techniques tended to have less water quality impairment than the surface applied treatment. At site 3, surface applied had significantly greater levels of nutrient and bacteria contamination than the injection methods. Since the bacteria tracer and chemicals were not found in tile water samples within a few days following the rainfall event, it appears that the impact of the manure application on tile water quality is relatively short lived.

The occurrence and concentration of the bacteria tracer and chemical tracers (strontium, chloride, bromide) in the tile water in the short time period after manure application, was confirmation that manure was the source. Tables 10 and 11 show the percent of applied tracers measured in the tile water after manure application, and after the simulated rainfall event, respectively. Increased tile flow following manure application represented about 1 to 2% of the applied manure at Site 1 where the tiles were flowing at the time of manure application. About 12% of the applied volume of simulated rainfall was recovered in the tile drains. Both the reactive (strontium) and non-reactive (chloride and bromide) tracers were found in the tile water after manure application and the simulated rainfall event. While <1% of the applied strontium was measured in the tile water, it provides evidence that the larger macropores were contributing pathways. Further evidence of macropore flow pathways for the applied manure was the short time period (7-10 min) after manure application that tile flow increased and bacteria tracer and chemical presence were measured. The strontium found in the pan water from the micro plots immediately following application also supports the suggestion of macropore flow being a major contributor to tile water contamination. The percent of applied anionic tracers (chloride, bromide) in the tile water measured after manure application and the simulated rainfall event was 2 to 3%. The percent of applied non-reactive tracers recovered was similar to the percent of applied volume of manure measured in the tile drains.

At Sites 2 and 3 where tile flow at the time of manure application was minimal, tile flow increases represented < 1% of the applied manure (Table 10). The percent of applied rainfall measured in the tile drains was 12% and 4% for Sites 2 and 3, respectively (Table 11). While the anionic tracer (bromide) was detected in the tile water both after manure application and simulated rainfall, the percent of applied bromide detected in the tile water was <1%. Similar to Site 1, the percent of applied non-reactive tracer measured in the tile drains approximated the percent of applied manure volume reaching the tile drains.

All liquid manure application methods resulted in tile water contamination immediately following manure application when the tiles were flowing, and following the simulated rainfall event. In a no-till system, the only way to stop tile water contamination may be to only apply liquid manure during the growing season when the soil is drier and the tiles are not flowing. Injection methods seem to decrease tile water contamination compared to surface applied, on medium to light textured soils, especially when the soil is at a low soil moisture content.

Table 10. Percent of applied manure and tracers reaching the tile drains following liquid manure application for the three study sites (^{1}Year 1, ^{2}Year 2).

Site-parameter	Modified Injection		Conventional Injection		Surface Applied		Control		Field Average	
	Y1^1	Y2^2	Y1^1	Y2^2	Y1^1	Y2^2	Y1^1	Y2^2	Y1^1	Y2^2
1- Manure	1.4	1.0	1.6	0.8	2.5	0.3	0.0	0.0	1.8	0.7
2- Manure	0.0	0.0	0.0	0.7	0.0	0.3	0.0	0.0	0.0	0.3
3- Manure	0.2		0.1		0.1		0.0		0.13	
1-Strontium	0.04		0.03		0.08		0.0		0.05	
1-Chloride	2.0		1.8		2.4		0.0		2.1	
1- Bromide		1.4a		0.2b		0.2b		0.0		0.6
2- Bromide	0.0	0.001	0.0	0.02	0.0	0.02	0.0	0.0	0.0	0.01
3- Bromide	0.003		0.01		0.001		0.0		0.005	

Means in the same column and followed by the same letter do not differ significantly according to Duncan's Multiple Range Test ($p>0.1$).

Table 11. Percent of applied manure and tracers reaching the tile drains following a simulated rainfall event for the three study sites (^{1}Year 1, ^{2}Year 2).

Site-parameter	Modified Injection		Conventional Injection		Surface Applied		Control		Field Average	
	Y1^1	Y2^2	Y1^1	Y2^2	Y1^1	Y2^2	Y1^1	Y2^2	Y1^1	Y2^2
1-Rain water		10.3		8.1		9.4		10.7		9.6
2-Rain water	0.5	8.1a	0	14.0b	2.4	13.2ab	1.1	13.4	1.3	12.1
3-Rain water	2.7		3.0		7.8		1.5		3.8	
1-Strontium										
1-Chloride										
1- Bromide		2.7a		1.3b		1.9ab		0.0		2.0
2- Bromide	0.2	0.29	0.0	0.24	0.29	0.84	0.0	0.0	0.16	0.46
3- Bromide	0.4a		0.6a		1.3b		0.0		0.8	

Means in the same column and followed by the same letter do not differ significantly according to Duncan's Multiple Range Test ($p>0.1$).

The use of liquid manure injection techniques to supply crop nitrogen needs by side dress application at the fourth leaf stage had the potential of reducing plant populations by excessive soil disturbance, and reducing yield through reduced nitrogen availability or seedling burn. Table 12 shows both the plant populations and crop yields for the control (inorganic fertilizer) and manure treated plots. Since there were no significant differences in yield among manure application techniques, the manure treatment yields were averaged. Yields were marginally less for the manure treatments in 2 of the 5 crop years studied but not statistically different for any year. Plant populations for the manure treatments were less in 3 of the 5 crop years. Plant damage by soil disturbance during manure injection was observed to be a significant problem on the clay textured soil.

Table 12. Crop response to liquid manure and inorganic fertilizer (control) application to no-till corn

Site	Year	Plant Population (pl/ha)		Yield (t/ha)	
		Manure Treatments	Control	Manure Treatments	Control
1	1994	66042	67623	8.538	7.647
1	1995	59805	64524	7.977	8.158
2	1995	66121	60260	9.062	9.218
2	1996	63267	72207	6.999	8.454
3	1996	68925	71238	6.625	6.780

The tractor energy consumption data clearly show the extra power and energy required for the modified injection configuration over the conventional injection. However, the difference is relatively small. McLaughlin et al. (1997) found that the modified injection configuration with a leading coulter and 50 mm wide cultivator spike followed by 50 mm wide injectors had a smaller draft requirement than a tanker with conventional 570 mm wide duck foot injectors. The modified injection configuration is considered practical from an energy perspective.

A tile drainage model that predicts both water quantity and quality parameters for agricultural landscapes would be useful to extrapolate the detailed results for the 3 soil and crop management conditions of this study. DRAINMOD (Skaggs, et. al., 1990) which includes a water quantity component and no water quality outputs at this time was used to predict tile flow rates with two years of growing season (May to November) tile flow data from Sites 1 and 2. The model was run for the entire year with measured soil and climatic input variables and default values for hydrologic properties such as lateral hydraulic conductivity that were not measured at the site. When 2 of the model's most sensitive properties (depth to impermeable layer and lateral hydraulic conductivity) were optimized, realistic tile flow values were obtained for both Sites 1 and 2. Statistical analysis showed that there were usually no differences between measured and predicted flows for each of the 12 tiles at a study site. When differences in flow were observed, the model tended to over estimate (Site 1- 33%, Site 2- 58%) actual values. The DRAINMOD model does not appear to be reflecting any macropore flow component. This shortfall was evident in rainfall/tile flow events where actual tile flow was consistently initiated well before the predicted flow. At this time, the DRAINMOD model is being modified to include a water quality component. Results of this evaluation of the water quantity component of the model are positive enough to consider further study of the water quality modifications to the model when available.

Study results have lead to the following recommendations for the application of liquid manure in no-till corn production systems:

i) Liquid manure nutrient testing is required immediately prior to manure application to establish accurate manure application rates.

ii) Side dress injection or surface application, at the fourth leaf stage, of liquid manure at soil test recommended rates will produce corn yields equivalent to conventional inorganic N fertilization.

iii) Conventional and modified injection equipment tested are recommended for use on medium to light textured soils.

iv) Side dressed injection applications should be considered to reduce impacts on tile water quality relative to surface applications especially on medium and light textured soils.

v) Apply liquid manure to tile drained land when the tile drains are not flowing to reduce impacts on tile water quality.

6.0) REFERENCES

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Appendix A
Detailed Soil Information for the Three Study Sites

Detailed Soil Information for Site 1

Soil Series: Crombie
Drainage: Poor
Site: Pit # 1

Horizon	**Depth** cm	**Texture**	**Sand** %	**Silt** %	**Clay** %	**pH** $CaCl_2$	**CaCo3** %	**OM** %	**Pb** gm/cc	**Ksat** cm/hr
Apk	0-25	SIL	35	50	15	7.2	1.4	3.1	1.31	13.2
Ckgj	25-42	FSL	70	24	6	7.5	14.3	0.5	1.51	0.2
Ckg1	42-52	L	51	41	9	7.6	28.4	0.4	1.72	0.6
Ckg2	52-85	L	52	37	11	7.6	24.9	0.3	1.89	1.5

Soil Series: Embro
Drainage: Imperfect
Site: Pit # 2

Horizon	**Depth** cm	**Texture**	**Sand** %	**Silt** %	**Clay** %	**pH** $CaCL_2$	**CaCo3** %	**OM** %	**Pb** gm/cc	**Ksat** cm/hr
Ap	0-25	SIL	24	57	19	6.8	1.0	5.6	1.16	1.9
Bmgj	25-50	L	51	37	12	7.2	1.7	0.4	1.55	0.04
Ckg	50+	SIL	37	53	10	7.6	24.6	0.4	1.56	0.1

Detailed Soil Information for Site 2

Series: Brisbane
Drainage: Imperfect
Site: Pit # 1

Horizon	Depth cm	Texture	Sand %	Silt %	Clay %	pH CaCl$_2$	CaCo3 %	OM %	Pb gm/cc
Ap	0-30	L	45	45	10	6.9	1.7	3.9	1.29
Bm	30-44	L	48	42	10	6.9	0.2	1.7	1.46
Bmgj	44-75	FSL	61	30	9	7.2	3.8	0.5	1.46
Ckgj	75-87	GFSL	69	26	5	7.3	24.2	0.1	1.43
Ckg	87+	FSL	52	43	5	7.7	28.4	0.4	

Series: Brisbane
Drainage: Imperfect
Site: Pit # 2

Horizon	Depth cm	Texture	Sand %	Silt %	Clay %	pH CaCL$_2$	CaCo3 %	OM %	Pb gm/cc
Ap1	0-17	L	45	42	13	7.0	1.2	4.3	1.27
Ap2	17-26	L	43	45	12	7.2	0.8	3.4	1.21
Bm	26-42	L	45	41	14	7.3	1.6	1.8	1.49
BC	42-53	GL	48	39	13	7.4	4.9	1.0	
Ck	53-69	GSL	74	20	6	7.5	12.8	0.7	
Ckg	69-90	L	44	45	11	7.8	30.6	0.3	1.82

Detailed Soil Information for Site 3

Series: Perth
Drainage: Moderately Well
Site: Pit # 1

Horizon	Depth cm	Texture	Sand %	Silt %	Clay %	pH CaCL$_2$	CaCo 3 %	OM %	Pb gm/cc
Ap1	0-18	SICL	12	54	34	6.0	1.3	3.1	1.31
Ap2	18-28	SICL	12	55	33	6.2	0.6	2.6	1.51
Bmgj	28-44	SIC	8	48	44	6.7	1.2	1.0	1.52
Ckgj	44-90	SICL	17	48	35	7.4	30.9	0.5	1.6
Ckg	90-124	SIC	6	46	48	7.4	29.4	0.7	1.74

Appendix B

DRAINMOD Model Inputs and Atatistical Analysis

Tile drain depths for Sites 1 and 2.

	Drain Depth (cm)	
Tile #	**Site 1**	**Site 2**
1	79	83
2	87	84
3	107	80
4	84	87
5	87	74
6	87	73
7	83.5	75
8	82	75
9	86.5	74
10	87.5	87
11	83.5	87
12	90.5	78

Trafficability inputs for DRAINMOD for Site 1

Variable	1st Work Period	2nd Work Period
MOBW	5	10
IDABW	5	20
MOEW	6	11
IDAEW	1	30
SWKHR	8	8
EWKHR	20	20
AMIN	3.7	3.9
ROUTA	0.7	0.5

Variable	1st Work Period	2nd Work Period
ROUTT	1	1

General Crop Inputs for DRAINMOD for Site 1

Variable	Value
ISEWMS	6
ISEWDS	1
ISEWME	8
ISEWDE	18
SEWX	20
IDRYMS	5
IDRYDS	10
IDRYME	9
IDRYDE	1

Statistical Comparison of Modelled Results to Measured Tile Flow for Site 1

1994 P-Values					
Tile #	**May**	**June**	**July**	**August**	**September**
1	0.1386	0.9790	0.1301	**0.0345***	0.0979
2	0.0573	1.0	0.1248	N/A	N/A
3	**0***	0.0798	0.0641	**0.001***	**0**
4	0.5100	0.2443	**0.0477***	0.2292	**0.0979***
5	**0.0047***	0.6099	**0.001***	0.0876	0.0980
6	**0.0314***	0.8562	**0.0037***	N/A	0.0979
7	0.1773	**0.0500***	**0.0022***	0.0780	1.0
8	0.5974	0.0833	**0***	0.1555	1.0
9	**0.0295***	**0.0498***	**0.0088***	1.0	0.0781
10	0.1948	0.0980	**0***	**0.0390***	1.0
11	**0.0001***	0.1308	**0.0545***	**0.0383***	1.0
12	0.6505	0.7536	0.001	0.6983	1.0

***** indicates a significant difference using Least Significant Difference test(>0.05).

Statistical Comparison of Modelled Results to Measured Tile Flow for Site 1

1995 P-Values					
Tile #	**May**	**June**	**July**	**August**	**September**
1	1.0	0.0804	0.9815	0.1032	0.0779
2	0.1174	**0.0099***	0.9789	**0.0034***	0.0907
3	0.2054	0.0897	0.0675	**0.0044***	**0.0015***
4	0.1583	**0.0376***	0.2626	0.3451	0.1555
5	0.2550	0.5799	0.8922	**0.0006***	0.0779
6	0.2164	0.3913	0.6087	0.4541	0.0779
7	0.0901	**0.0001***	**0.0383***	0.1488	1.0
8	0.4857	0.1250	0.0786	1.0	0.1606
9	0.7909	**0.0238***	0.6618	0.2752	1.0
10	0.3519	**0.0235***	0.2442	1.0	0.1916
11	0.3351	0.1504	0.0827	0.1606	1.0
12	0.8587	0.0528	0.5205	1.0	0.4177

***** indicates a significant difference using Least Significant Difference test(>0.05).

Statistical Comparison of Modelled Results to Measured Tile Flow for Site 2

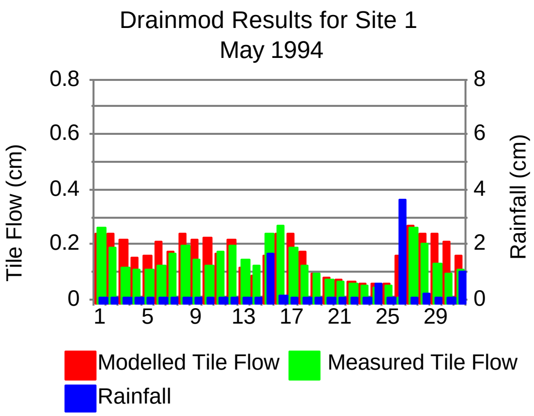
1995 P-Values					
Tile #	**May**	**June**	**July**	**August**	**September**
1	0.1025	0.0117	0.1523	N/A	1.0
2	0.4931	0.4039	0.5176	N/A	1.0
3	0.2134	0.0477	**0.0205***	N/A	1.0
4	0.8643	0.2413	**0.0027***	N/A	1.0
5	0.4622	0.1637	0.2582	N/A	1.0
6	0.8836	0.7498	0.8452	N/A	1.0
7	0.9489	0.7920	0.0596	N/A	1.0
8	0.8011	0.9905	0.1342	N/A	1.0
9	0.8742	0.7147	**0.0323***	N/A	1.0
10	0.7973	0.6412	**0.0019***	N/A	1.0
11	0.8091	0.2171	**0.0248***	N/A	1.0
12	0.8556	0.8454	**0.0162***	N/A	1.0

***** indicates a significant difference using Least Significant Difference test(>0.05).

Statistical Comparison of Modelled Results to Measured Tile Flow for Site 2

1996 P-Values			
Tile #	**May**	**June**	**July**
1	**0.0367***	0.6037	**0***
2	**0.0006***	0.9499	**0***
3	**0***	0.8281	**0***
4	**0.0405***	0.6387	**0***
5	**0.0178***	0.9948	**0***
6	0.4759	0.6475	**0***
7	0.1711	0.7399	0.0736
8	0.4489	0.3948	0.6457
9	0.4720	0.7171	0.0736
10	**0.0002***	0.9691	**0.0022***
11	**0***	0.5295	**0.0022***
12	0.1235	0.4154	**0.0460***

***** indicates a significant difference using Least Significant Difference test(>0.05).


Drainmod Results for Site 1
May 1994
Tile Flow (cm)
Rainfall (cm)
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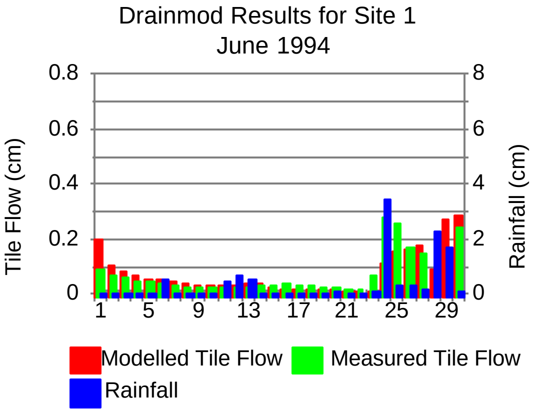
Modelled Tile Flow
Measured Tile Flow
Rainfall


Drainmod Results for Site 1
June 1994
Tile Flow (cm)
Rainfall (cm)
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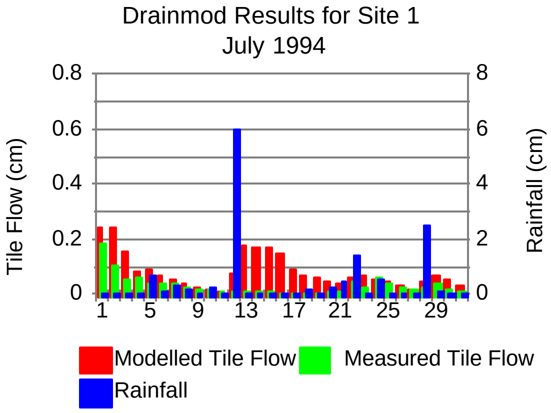
Modelled Tile Flow
Measured Tile Flow
Rainfall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Tile Flow (cm)
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Modelled Tile Flow
Measured Tile Flow
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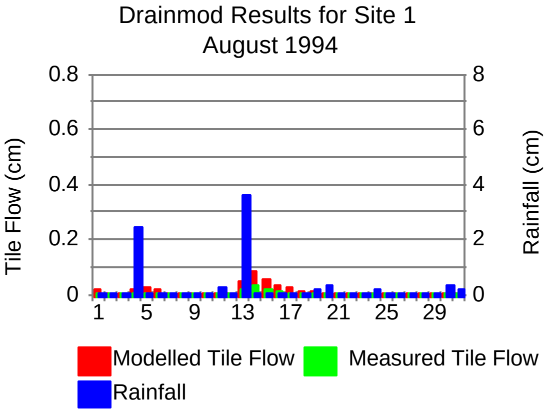
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August 1994
Tile Flow (cm)
Rainfall (cm)
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Modelled Tile Flow
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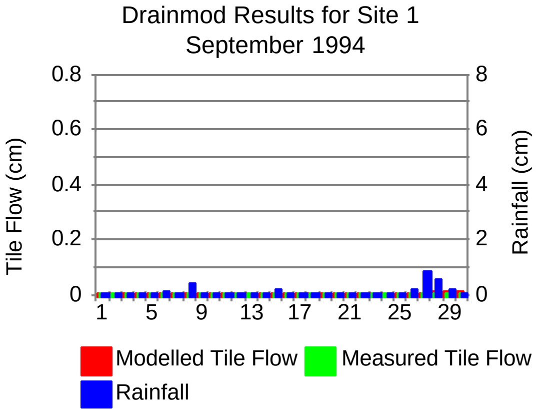
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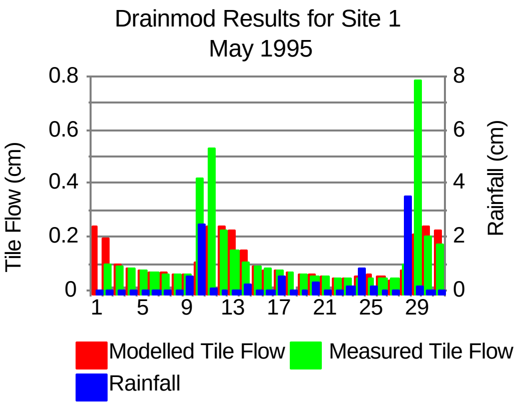
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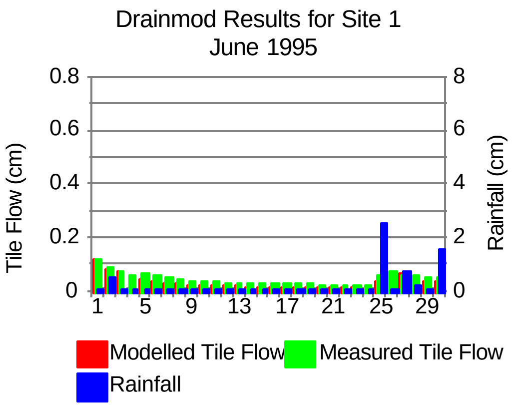
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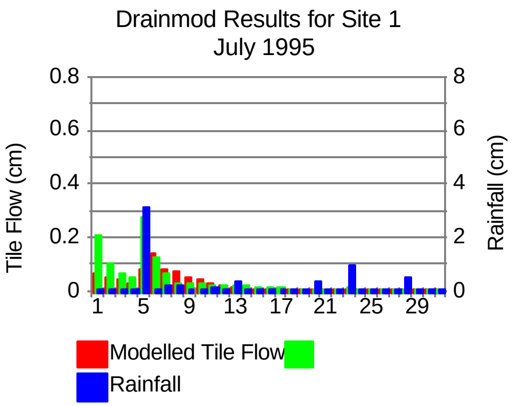
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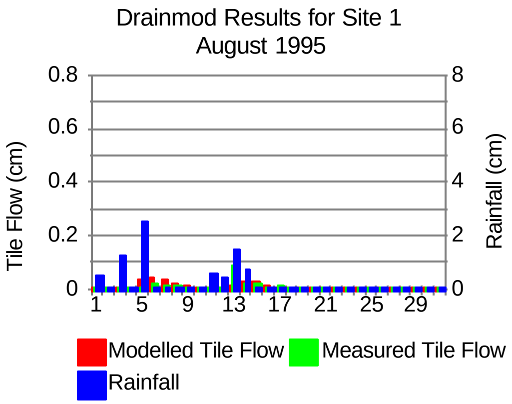
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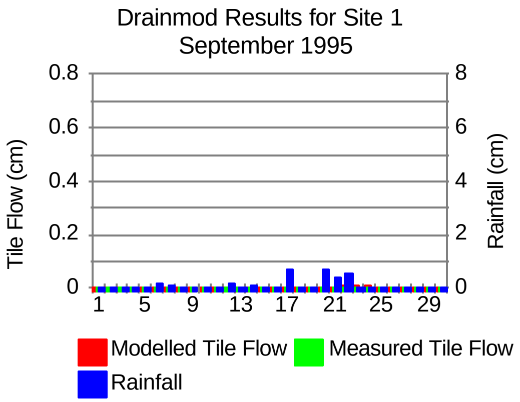
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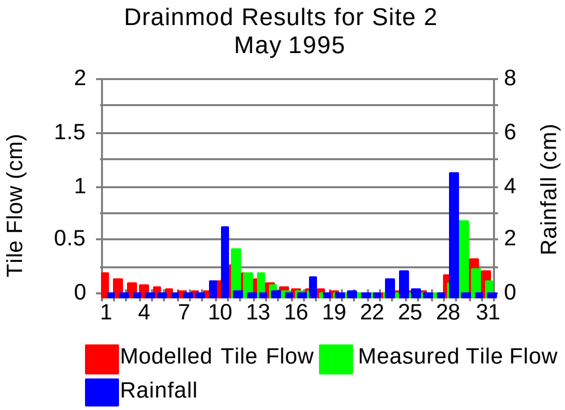
Drainmod Results for Site 2
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Tile Flow (cm)
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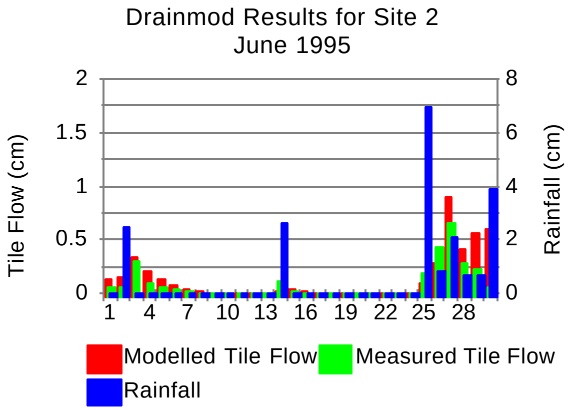
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June 1995
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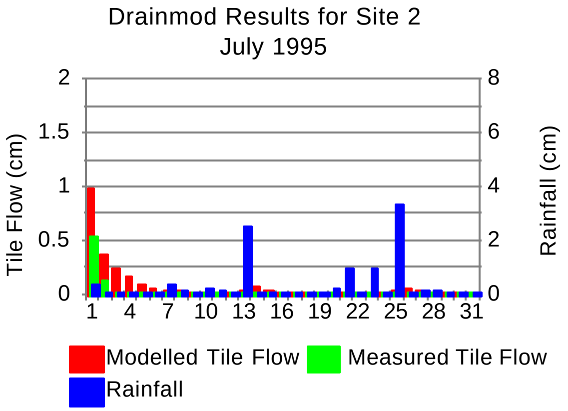
Drainmod Results for Site 2
July 1995
Tile Flow (cm)
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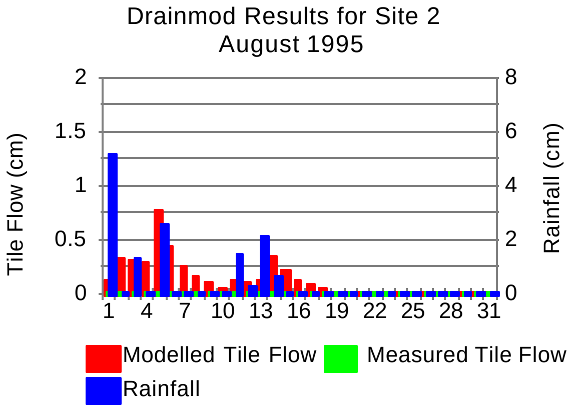
Drainmod Results for Site 2
August 1995
Tile Flow (cm)
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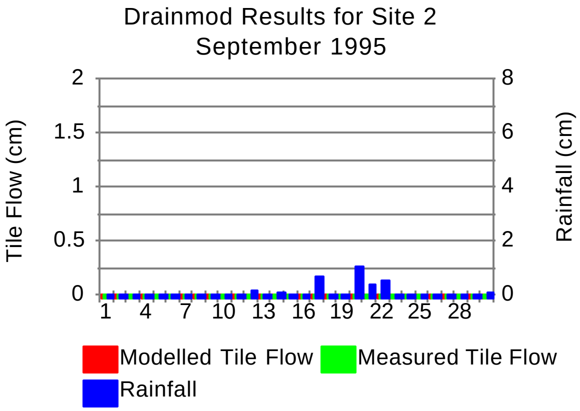
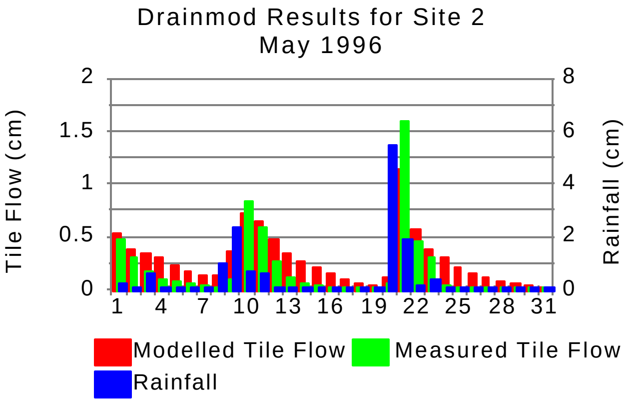
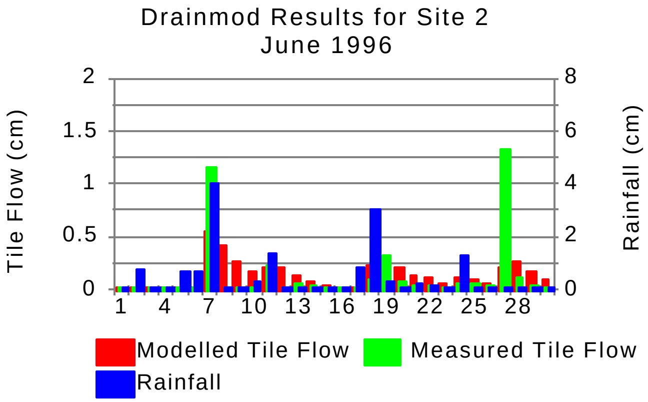
2
0
1
4
7
10
13
16
19
22
25
28
31
🟥 Modelled Tile Flow
🟩 Measured Tile Flow
🟦 Rainfall

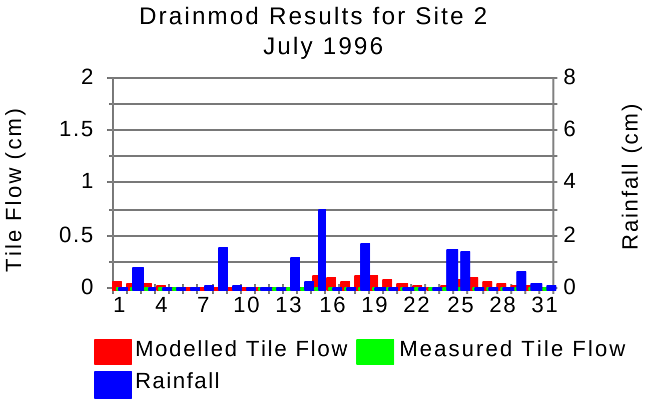

Drainmod Results for Site 2
September 1995
Tile Flow (cm)
Rainfall (cm)
2
1.5
1
0.5
0
8
6
4
2
0
1
4
7
10
13
16
19
22
25
28
🟥 Modelled Tile Flow
🟩 Measured Tile Flow
🟦 Rainfall



Drainmod Results for Site 2
May 1996



Drainmod Results for Site 2
June 1996



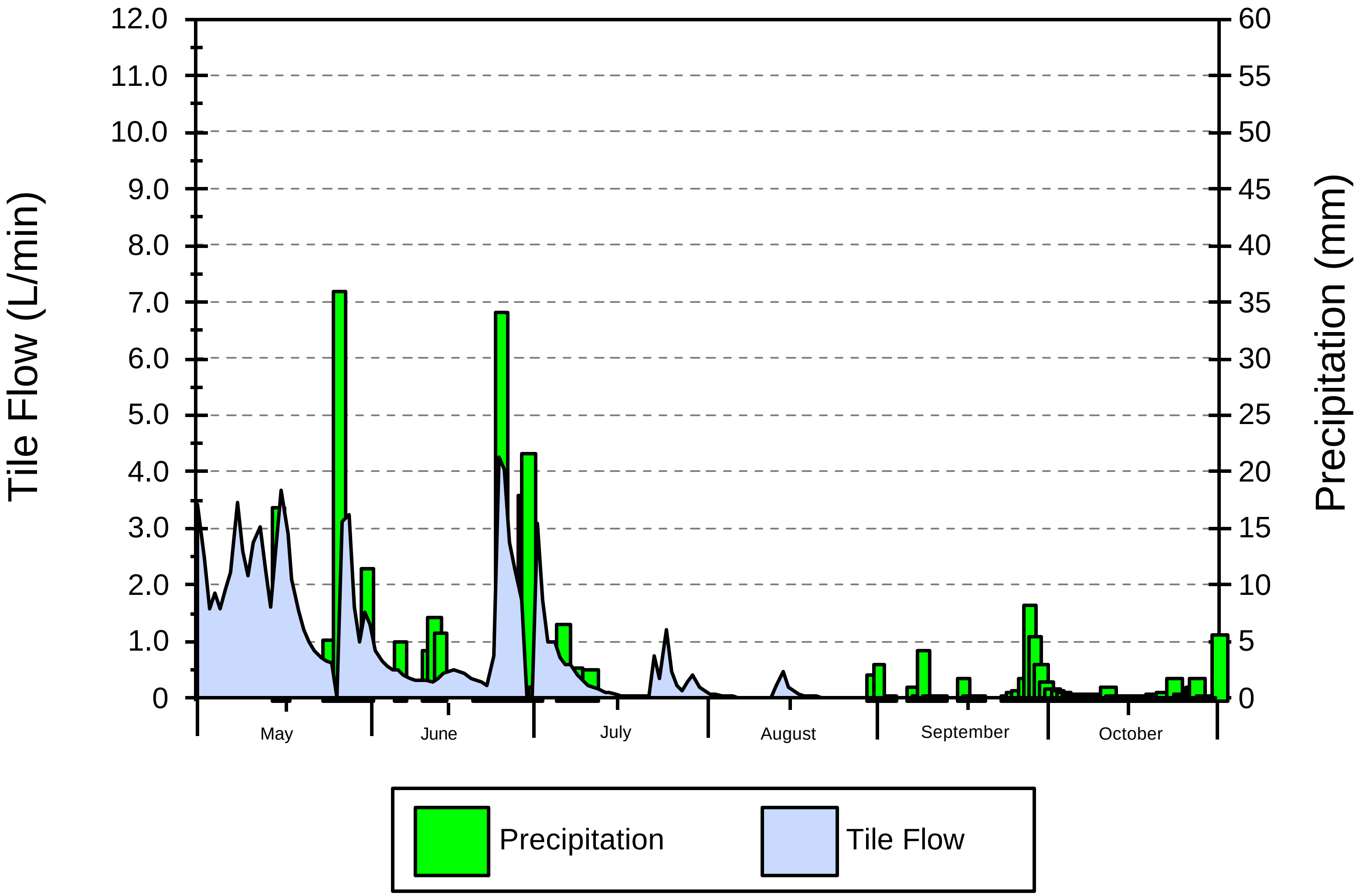
Drainmod Results for Site 2
July 1996

Appendix C

Seasonal Hydrographs for the Three Study Sites

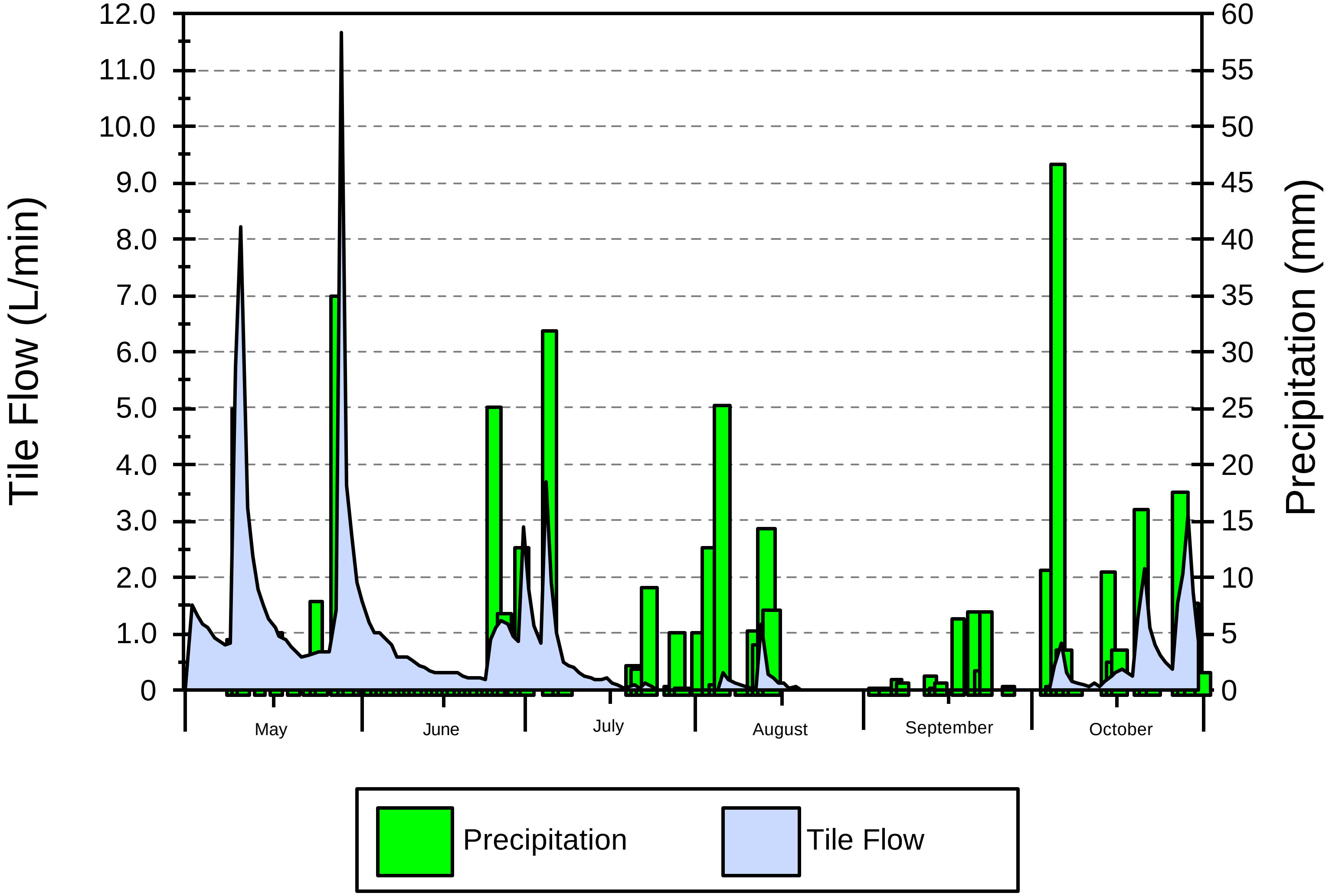
1994 Seasonal Tile Flow - Site 1

Tiles 1 - 12



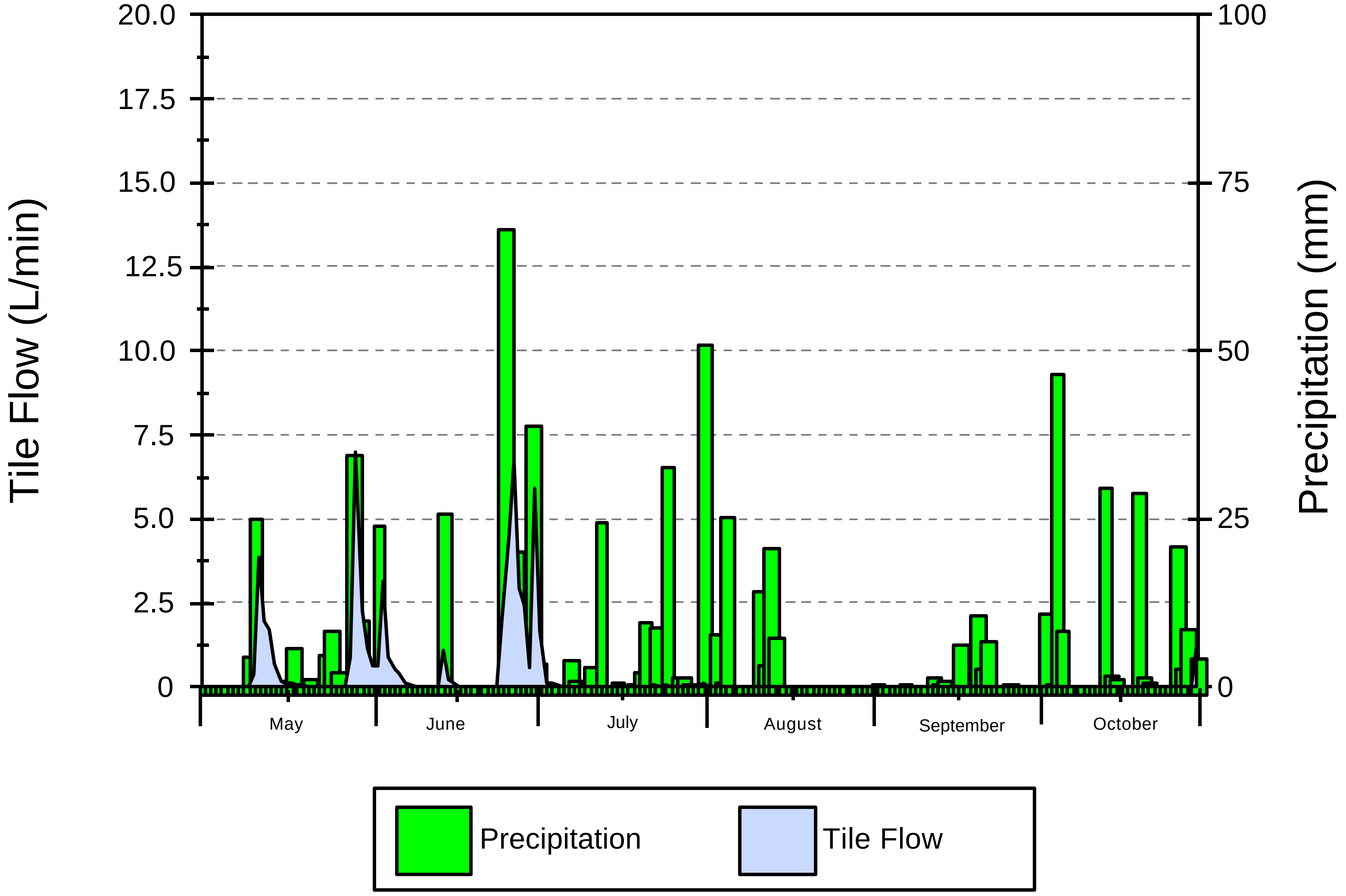
1995 Seasonal Tile Flow - Site 1

Tiles 1 - 12



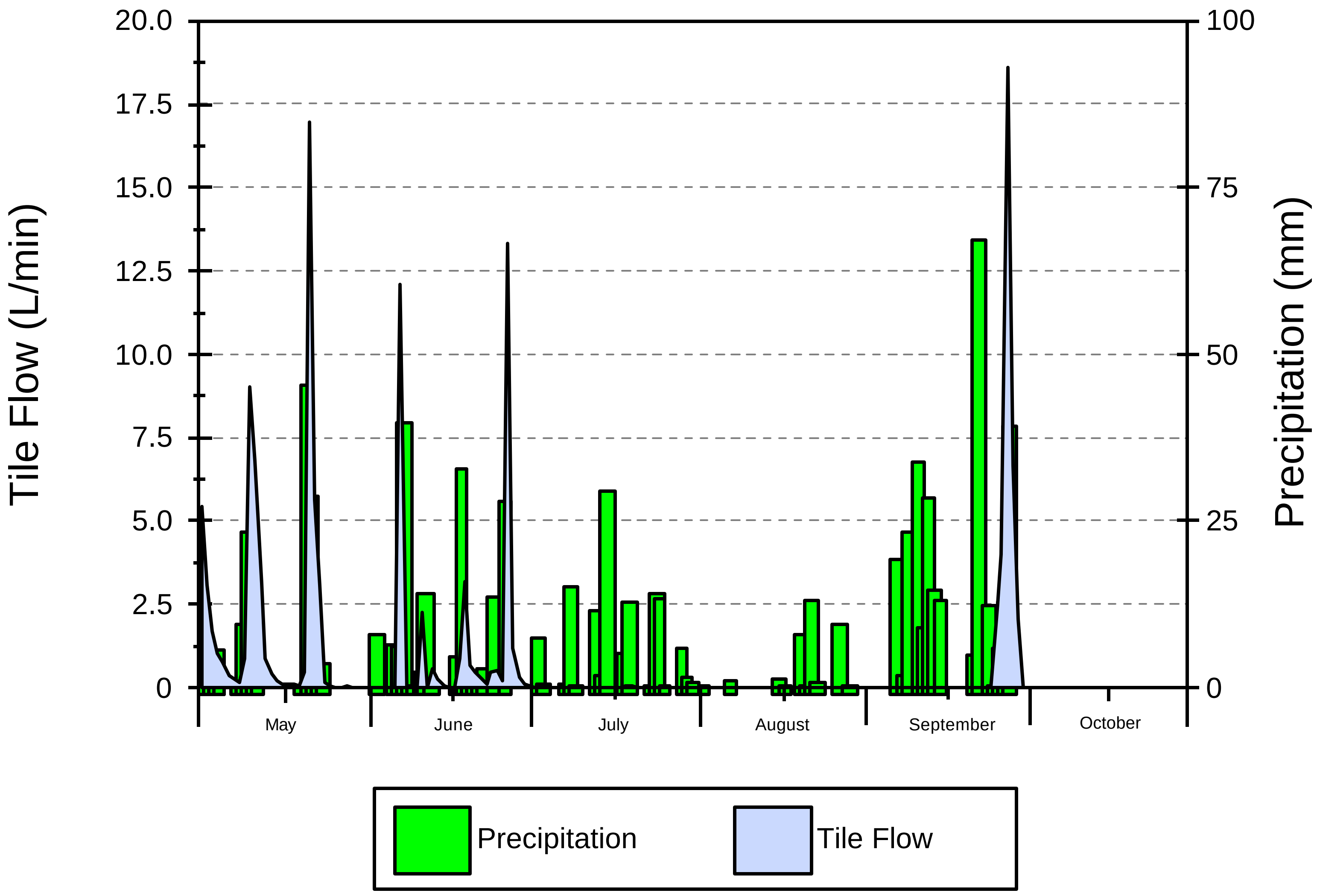
1995 Seasonal Tile Flow - Site 2

Tiles 1 - 12



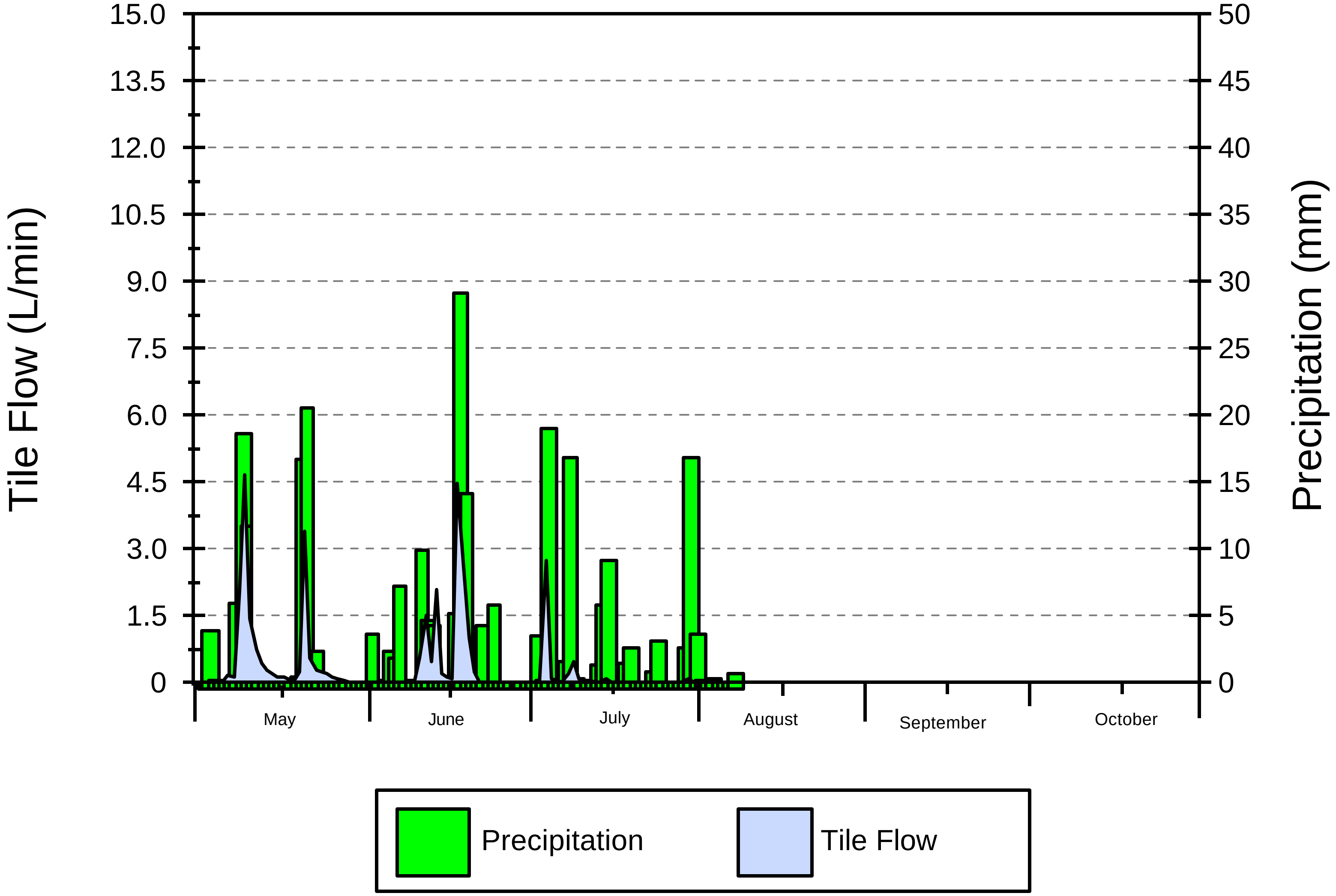
1996 Seasonal Tile Flow - Site 2

Tiles 1 - 12



1996 Seasonal Tile Flow - Site 3

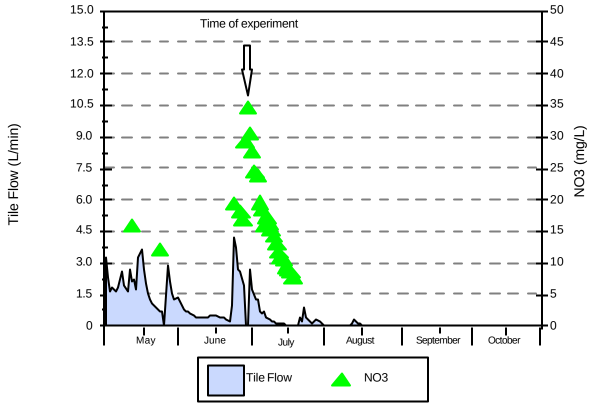
Tiles 1 - 12



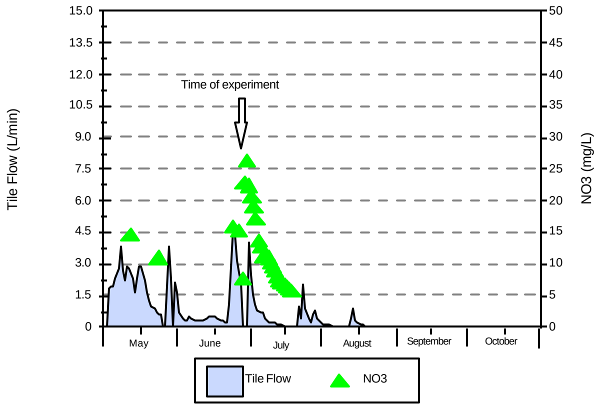
Appendix D
Seasonal Nitrate Concentrations for the Three Study Sites

1994 Tile Flow and Nitrate Levels - Site 1

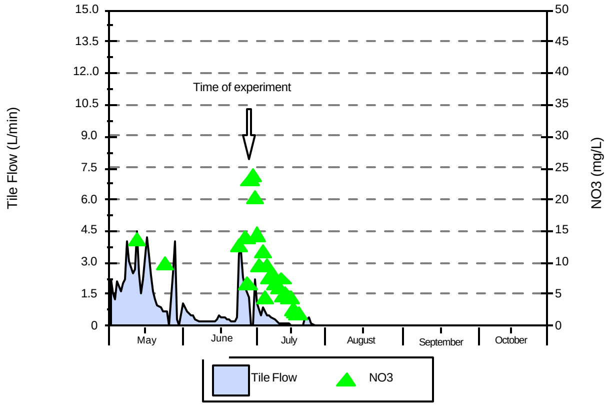
Control



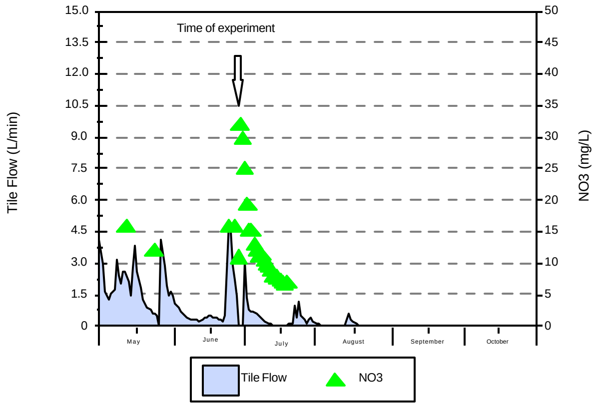
Modified Injection



Conventional Injection

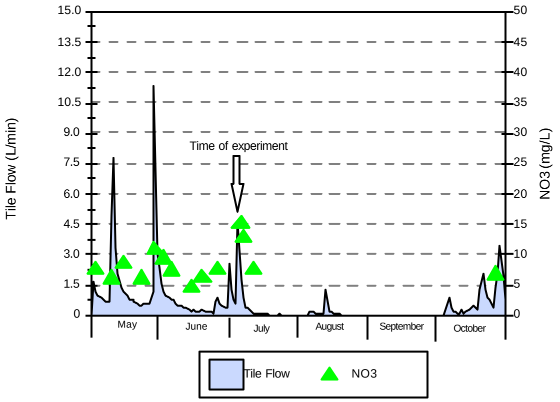


Surface Applied

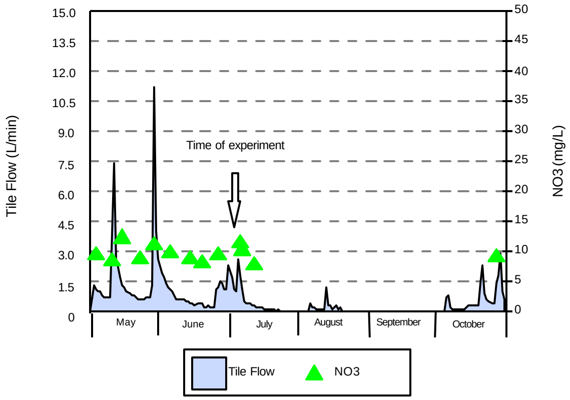


1995 Tile Flow and Nitrate Levels - Site 1

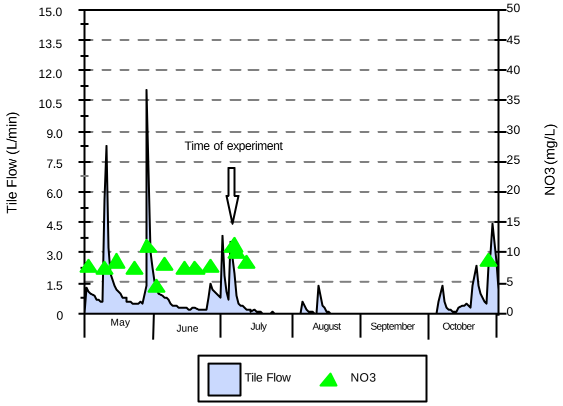
Control



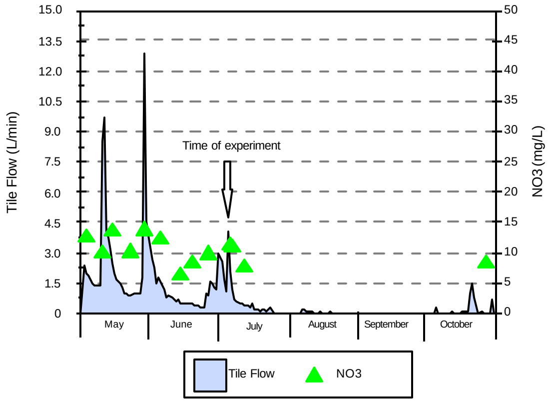
Modified Injection



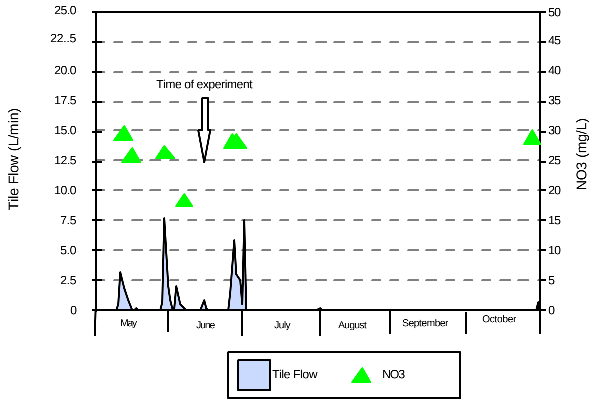
Conventional Injection

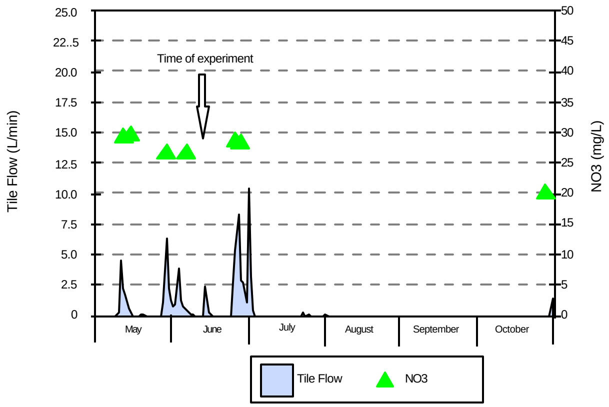


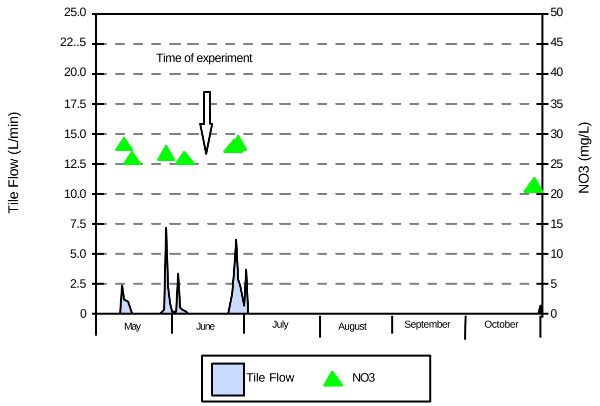
Surface Applied

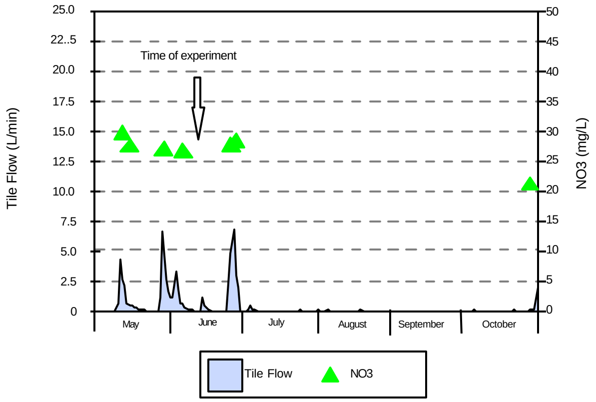


1995 Tile Flow and Nitrate Levels - Site 2


Control

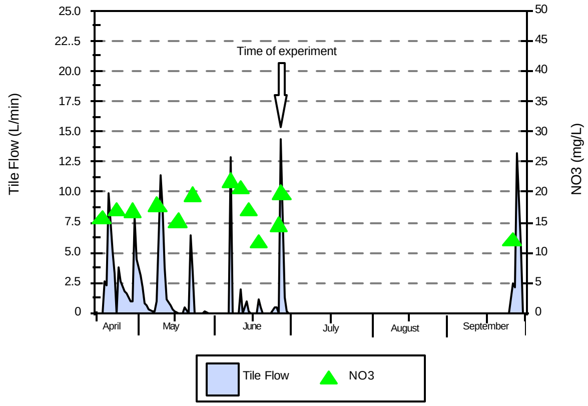

Modified Injection


Conventional Injection

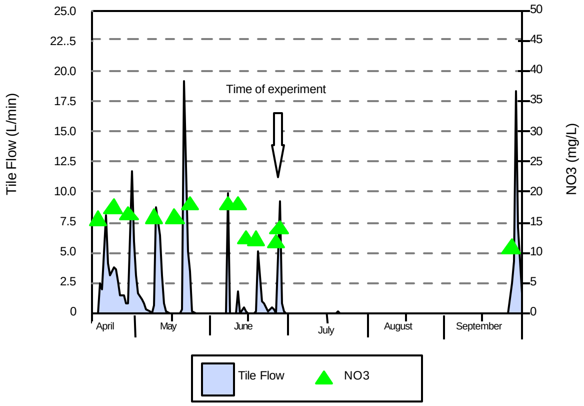

Surface Applied

1996 Tile Flow and Nitrate Levels - Site 2

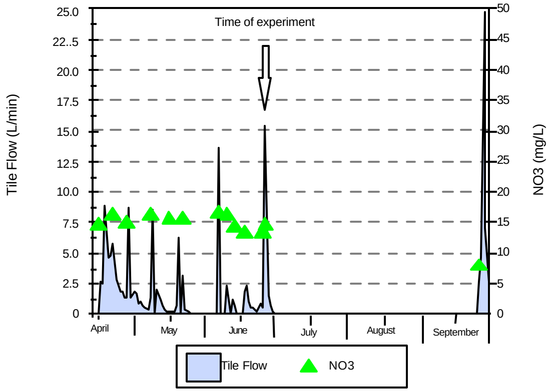
Control



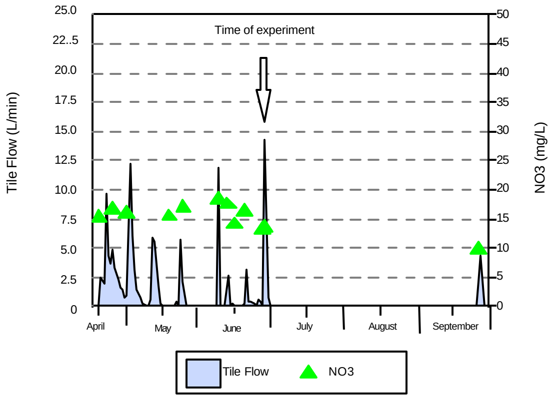
Modified Injection



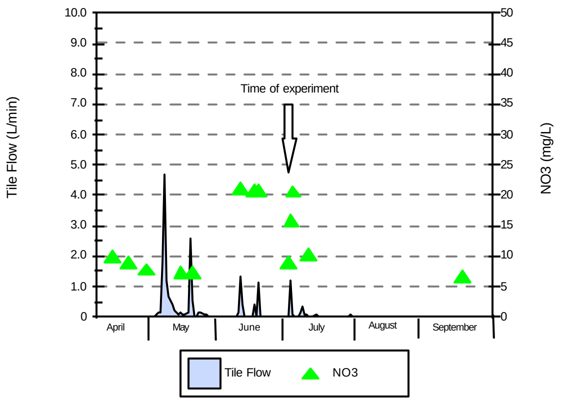
Conventional Injection



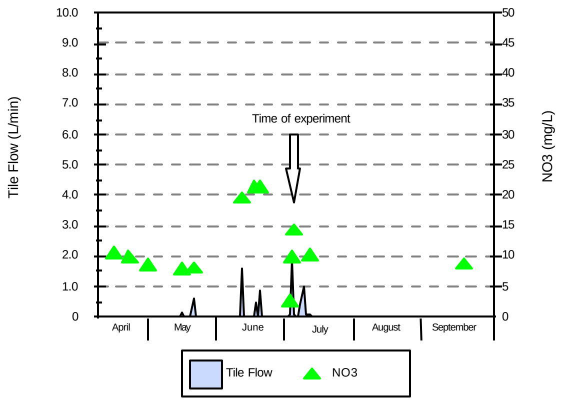
Surface Applied



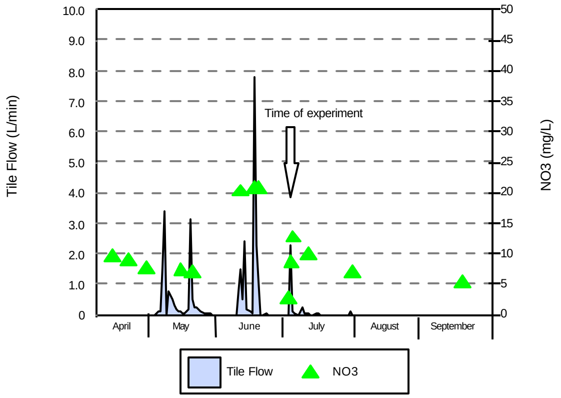
1996 Tile Flow and Nitrate Levels - Site 3



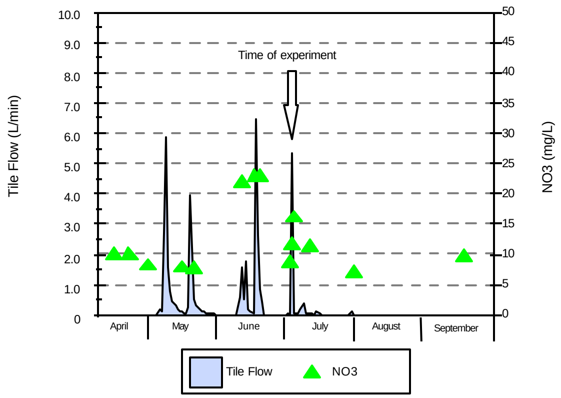
Control



Modified Injection



Conventional Injection



Surface Applied

Appendix E
Crop Management and Agronomic Information for the Three Study Sites

Crop management and agronomic information for each study site.

Activity		**Site 1 1994**	**Site 1 1995**	**Site 2 1995**	**Site 2 1996**	**Site 3 1996**
Planting	Date	May 31	June 1	May 16	May 27	May 30
	Rate (pl/ha)	74,100	74,100	73,400	76,100	74,100
	Variety	Pio 3790	Pio 3790	Pio 3790	Pio 3790	Pio 3723
	Depth (cm)	5	3.5	2.5	4	4
	Planter	NewIdeaNT 6R-3co/2fl/tr	NewIdeaNT 6R-3co/2fl/t	JD7000 4R-trash	JD7000 6R-trash	NewIdea 6R-3coulters
	Row width cm	76	76	91	76	76
	Insecticide	Counter	Force	None	None	None
	Rate (kg/ha)	7.8	7.8	0	0	0
Fertilizer						
Control	N-P-K	46-12-3 @351 kg/ha	10-34-0 @426 kg/ha	19-19-19 @298kg/ha	19-19-19 @392kg/ha	82-0-0 @90 lb/ac
	Rate (kg/ha)	161-18-5	140-11-0	57-25-47	75-33-62	74-0-0
	Date	May 31	June 1	May 16	May 27	June 30
Starter	N-P-K	6-24-6 @55 L/ha	10-34-0 @34 L/ha	6-24-24 / 12-52-0all @161/28	12-52-0 @28 kg/ha	18-18-18 @175 lb/ac
	Rate (kg/ha)	3-12-3	3-10-0	11-17-33cl 3-7-0 all	3-7-0	32-14-26
Manure	N-P-K	10.5-4.6-7.6	23-9.2-19.4	10-10-5.8	15-6-10	30-2-18
	Rate (L/ha)	69500	62900	71900	69500	56200
	Rate (kg/ha)	73-33-53	139-56-118	72-72-41	100-40-67	168-11-100
	Appl'n date	June 28	June 27	June 13	June 26	July 3
Herbicide	Control	grasses	grass/br.(dan)	excellent	exc.-v.corn	excellent
Pre-plant	Type	Roundup	RU/Dual	RU/Amitrol	Roundup	
	Rate (L/ha)	2.5 (May15)	2.5/2.2(M15)	3.7/3.7	2.5 (May25)	
Pre-emerge	Type				Banvel	RU/2,4-D
	Rate (L/ha)				0.6(M27)	2.5/1.2(Jn4)
Post-emerge	Type	2,4-D		Primextra		Atrazine/oil
	Rate (L/ha)	0.42 kg/ha		6.2		2#/12(Jn25)
Harvest	Date	Nov. 10	Oct. 31	Oct. 28	Nov. 29	Jan. 9/97

Soil nutrient analysis data of treatment plots before and after manure application.

Treatments are: C - Control, SA - Surface applied, CI - Conventional injection, MI - Modified injection

Application treatment

	C	C	C	SA	SA	SA	CI	CI	CI	MI	MI	MI	Avg
Site1-94													
N-6/21	116	95	181	78	78	76	83	87	59	86	65	81	90
N-7/12	139	109	120	100	137	146	228	125	265	221	138	181	159
P-6/21	35	19	17	16	17	13	21	17	14	12	14	20	18
K-6/21	111	120	120	104	157	69	102	123	145	115	107	121	116
P-7/12	20	15	14	20	16	23	21	15	17	16	17	13	17
Site1-95													
N-6/13	86	85	94	81	63	65	113	58	82	93	59	71	79
N-7/17	55	162	107	131	172	88	171	137	102	107	113	115	122
N-11/23	76	51	69	47	60	41	58	57	85	46	65	60	60
P-6/13	18	18	16	19	13	20	18	17	14	20	15	15	17
K-6/13	196	206	220	221	217	233	215	201	250	203	215	226	217
P-7/17	16	15	19	19	16	17	19	23	22	21	15	16	18
K-7/17	113	120	133	126	112	109	106	111	135	103	111	127	117
Site2-95													
N-6/5	103	100	147	75	70	73	74	93	82	119	95	75	92
N-7/17	92	115	96	72	92	46	64	65	68	59	78	54	75
N-11/23	48	50	69	46	51	58	58	53	58	60	63	66	57
P-6/5	19	11	15	21	27	21	11	12	30	17	18	12	18
K-6/5	176	164	165	148	185	140	167	166	142	182	134	117	157
Site2-96													
N-6/14	295	272	257	101	100	82	101	88	93	72	109	80	137
N-8/9	84	98	119	74	60	89	75	98	82	76	75	79	84
P-6/14	21	26	9	23	20	15	33	41	22	20	14	42	24
K-6/14	119	124	82	90	149	91	107	110	101	128	94	105	108
P-8/9	18	12	12	21	18	14	15	32	30	25	15	30	20
K-8/9	59	87	76	69	134	107	61	121	73	85	90	103	89
Site3-96													
N-6/21	17	59	66	64	24	65	17	76	68	19	67	53	50
N-9/19	89	39	34	47	29	44	45	51	26	45	37	30	43
P-6/21	26	23	19	24	16	45	23	26	27	17	18	22	24
K-6/21	139	268	148	128	212	168	170	251	172	137	234	148	181
P-9/19	22	21	49	22	20	21	26	47	14	26	28	17	26
K-9/19	162	182	173	142	137	176	150	173	142	141	195	152	160

N-Nitrogen in kg/ha P-Available phosphorus in mg/L soil (ppm) K-Available potassium in mg/L soil (ppm)