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Title: THE FERTILIZER VALUE OF SHRIMP AND CRAB PROCESSING WASTES

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The Federal Water Pollution Control Act Amendments of 1972 prohibits the discharge of seafood processing solid wastes into navigable waters after July 1, 1977. Oregon shrimp and crab processors must use other methods of disposal for the 15 to 30 million pounds of solid waste generated annually. The application of shrimp and crab wastes to nearby agricultural land can consume the wastes generated at major processing ports.

As they came from the processing plant, shrimp and crab solid wastes contained 1.3% to 1.6% N, 0.47% to 0.54% P, other nutrients, 7% to 14% $CaCO_3$ equivalent, and 64% to 78% water.

A greenhouse experiment was established to determine the effects of 1) grinding the wastes, 2) surface vs. incorporated waste applications, and 3) waste applications vs. inorganic N applied at equivalent N rates (56, 168, and 336 kg N/ha) with applications of P, S, and lime supplied with the inorganic N only. The fertilizer materials were applied on two coastal soils, and two pasture crops were grown. Forage yields and the P concentration in 'Potomac' orchard

grass (Dactylis glomerata L.) were significantly higher with incorporated waste applications than with surface waste applications. Application method did not affect the P concentration in New Zealand white clover (Trifolium repens L.). The difference in crop response between application methods would assumably be less under field conditions than was measured in the greenhouse. Grinding crab waste significantly increased forage yields when the waste was surface applied, but not when incorporated with the soil. Unground shrimp waste gave significantly higher forage yields than ground shrimp waste. No significant difference occurred in the forage yields, the N uptake by orchardgrass, or the P concentrations in orchardgrass and white clover among applications of shrimp waste, crab waste, and inorganic nutrients with lime. Applications of shrimp and crab wastes increased white clover yields over the control by a factor of more than 3.5 on Knappa silt loam (pH 4.9 - 5.0) but did not measurably increase the soil pH. It was assumed that the wastes, in the immediate area of the shell material, increased the availability of Ca, P, S, and Mo, decreased soluble soil Al, and allowed effective rhizobial nodulation and N fixation. Increasing application rates of shrimp and crab wastes to Knappa and Nehalem silt loams significantly increased the extractable soil P and Ca, and significantly decreased the extractable soil K after 28 weeks of orchardgrass growth. No consistent effect on soil pH was measured.

In a second greenhouse experiment, N rates of 165 and 330 kg/ha and P rates of 61 and 122 kg/ha were supplied by shrimp waste and by inorganic sources to a limed coastal soil in a 2 x 2 x 2 complete factorial arrangement. Applications of shrimp waste resulted in significantly higher orchardgrass yields and P uptake than applications of the inorganic nutrients, but no significant difference occurred in the N uptake.

In an irrigated coastal pasture, fresh shrimp waste was applied at 6,726, 17,936, and 35,872 kg/ha and ammonium phosphate (16-20-0 15 S) was applied at 224 and 448 kg/ha and a stand of orchardgrass was established. Forage yields were higher with shrimp waste than with ammonium phosphate. Shrimp waste applications beyond 17,936 kg/ha did not further increase the forage yield or P uptake. Shrimp waste applications increased extractable soil P, SO_4-S, soluble salts, and NO_3-N, but resulted in a depletion of soil K when measured at the end of the growing season.

Shrimp and crab processing wastes are effective sources of N and P for crop plants and should be applied at rates necessary to supply the recommended rates of N.

The Fertilizer Value of Shrimp and Crab Processing Wastes

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THE FERTILIZER VALUE OF SHRIMP AND CRAB PROCESSING WASTES

INTRODUCTION

Oregon seafood processors are currently generating 15 to 30 million pounds of shrimp and crab processing wastes annually. Shrimp solid waste consists of tail shells and heads, and crab solid waste consists of backs, entrails, and leg shells. The solid wastes are generally accompanied by a large volume of cooking, cooling, and washing water. Wastes are commonly discharged into adjacent bays and estuaries.

The Federal Water Pollution Control Act Amendments of 1972 requires "the application of the best practicable control technology currently available..." to limit discharge of point source pollutants into navigable waters by July 1, 1977. For most Oregon shrimp and crab processors, the federal regulations are satisfied by screening the wastes with a 40-mesh sieve to recover the solids. Liquids are discharged into adjacent bodies of water, into municipal waste-water systems, or moved to the next treatment system.

The federal act encourages the handling of recovered solids to allow for beneficial use, recycling, or disposal in a manner that will not result in environmental hazards. Shrimp and crab wastes are discharged into bays and estuaries, disposed of in landfills, or utilized as fertilizers, feed for commercial aquaculture species and monogastric and ruminant animals, and for the development of such industrially versatile by-products as chitosan. The amount of shrimp and crab wastes utilized in Oregon is quite small compared to the amount available. Fertilizer use can consume the amount of shrimp and crab wastes generated at major processing ports.

This research, sponsored by the Sea Grant College Program, was undertaken to determine the effects of shrimp and crab processing waste applications on agricultural land. The processing wastes were considered, for the purposes of this study, potentially useful fertilizer materials rather than refuse to be disposed of at high rates of application. Calcium, nitrogen, and phosphorus are the plant nutrient elements contained in shrimp and crab wastes in the highest concentrations. Nitrogen and phosphorus are valuable fertilizer nutrients, and commonly limit crop growth in Oregon coastal soils. A measure of the value of shrimp and crab processing wastes compared to alternate, conventional fertilizer materials will help to determine the economics of handling and transporting the waste material at and between the processing plant and the farm. Forage species were used to evaluate the fertilizer value of shrimp and crab wastes, as most of the agricultural land near seafood processing ports is utilized for pastures and forage production.

The objectives of this research were to determine:

1. the best ways to apply shrimp and crab processing wastes,
2. the effect of shrimp and crab waste applications on plant and soil chemical composition,
3. the value of shrimp and crab wastes compared to conventional fertilizer materials, and
4. reasonable application rates.

REVIEW OF THE LITERATURE

Oregon's Shrimp and Crab Industry

The shrimp species of commercial importance in Oregon is *Pandalus jordani*. These are small pink shrimp commonly used in shrimp cocktail and shrimp salad. Dungeness crab (*Cancer magister*), the primary crab species harvested in Oregon, are sold whole in the shell as well as butchered for their meat. Shrimp and crab meat is marketed either frozen or canned.

Landings and Waste Production

Substantial landings of *Pandalus* sp. are made in Alaska, British Columbia, Washington, Oregon, and California. Oregon shrimp landings (Figure 1) are second only to Alaska in the annual shrimp harvest in the Pacific Northwest. The shrimp catch has increased substantially since 1971, but may now be near the maximum sustainable yield. Cleary (1969) has estimated the potential annual catch of *P. jordani* for Oregon, Washington, and California to be 33 million pounds. The catch for these states in 1975 was 39 million pounds (Pacific Marine Fish Commission 1976).

The commercial shrimp season in Oregon (1976 regulations) runs from April 1 through October 15. The catch is relatively uniform throughout the season with somewhat smaller landings the first and last months (Figure 3). Oregon's shrimp processors are widely distributed along the coast (Table 1). Some ports, notably Astoria, are substantially expanding their processing capability. Approximately 78% to 85% of the live weight is waste when shrimp are processed with mechanical peelers (Jensen 1965).

The dungeness crab catch in Oregon has exhibited a somewhat cyclical nature (Figure 2). The fluctuations appear to be controlled by the extent of the previous years' hatch and the extent of harvesting (Soderquist et al. 1970).

Commercial crab season in Oregon (1976 regulations) runs from December 1 through August 15. The greatest landings occur early in the season and the catch generally tapers off throughout the remainder of the season (Figure 4). Crab landings in Oregon occur at most major fishing ports (Table 2). Waste production is quite variable. About 30% to 60% of the crab landed in Oregon is sold in the shell (Kreag and Smith 1973; Willis 1976). The actual amount varies widely from port to port and season to season. Approximately 76% to 80% of the live weight is waste after manual meat extraction from dungeness crab (Jensen 1965). Several processors are

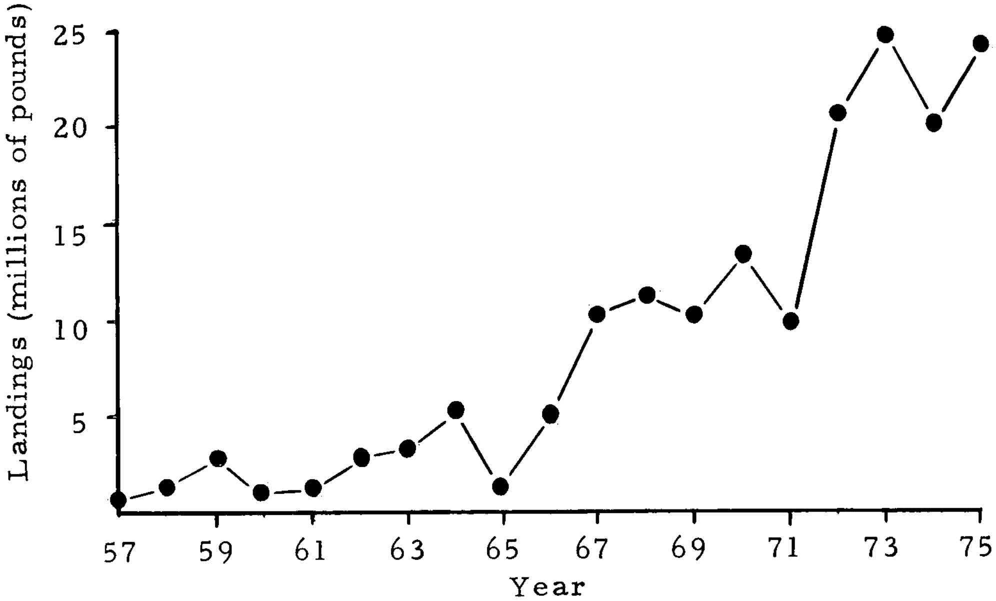

Figure 1. Oregon shrimp landings by year, 1957-75.

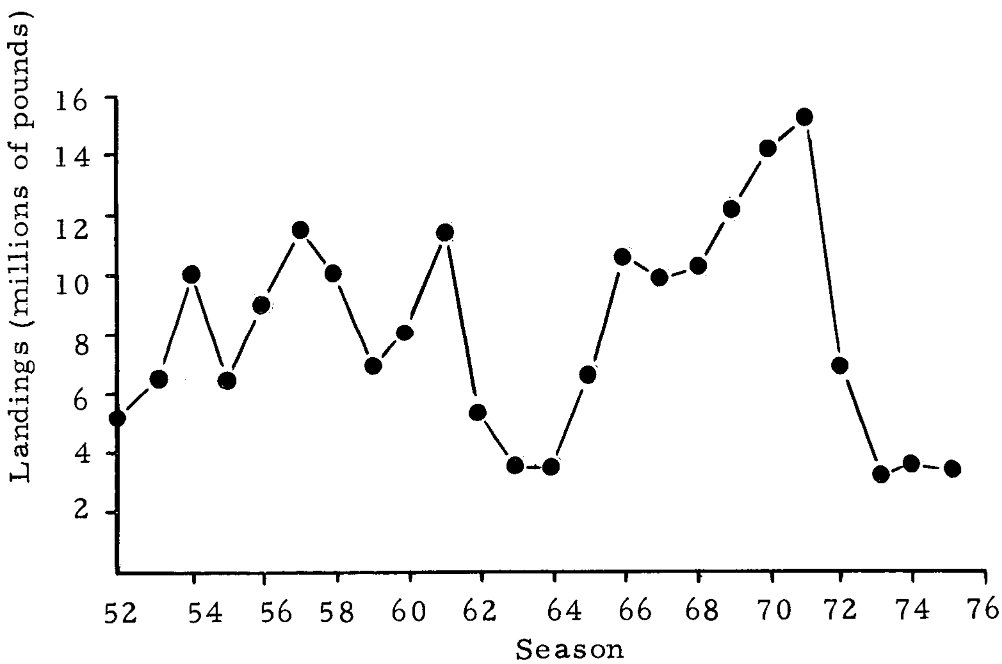

Figure 2. Oregon dungeness crab landings by season, 1952-75.

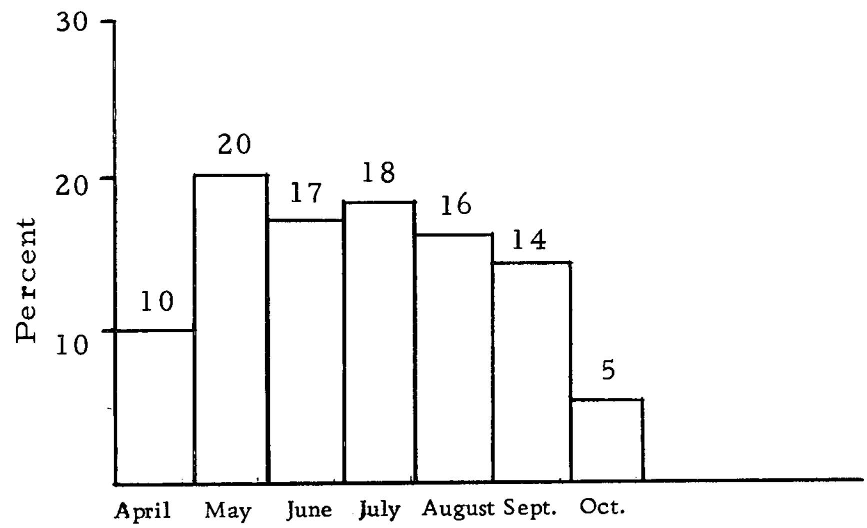

Figure 3. Percent of total annual shrimp landing by month.

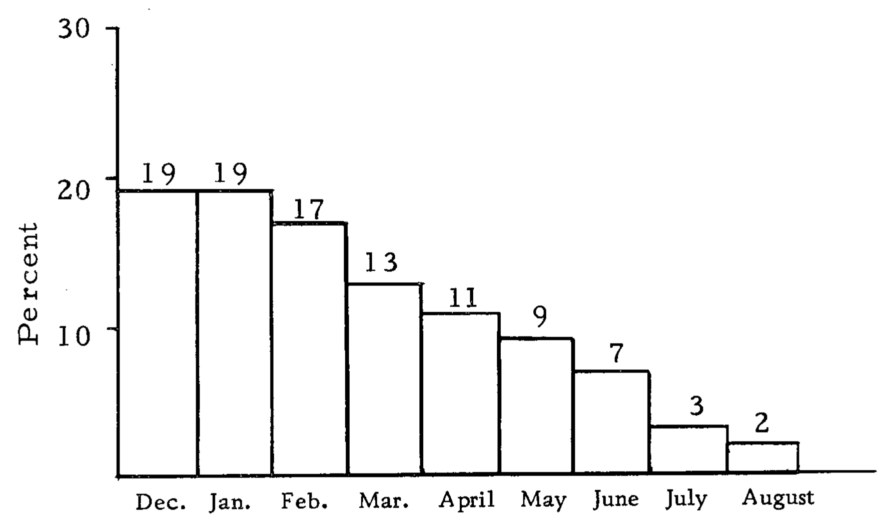

Figure 4. Percent of total annual crab landing by month.

Table 1. Shrimp landings and estimated waste production in Oregon, 1972.

Port	Landings[1]	Estimated Waste Production[2]
	---------thousands of pounds---------	
Astoria	2,360	1,888
Tillamook	1,910	1,528
Newport	7,330	5,864
Winchester Bay	810	648
Coos Bay	5,410	4,328
Port Orford	1,220	976
Brookings	1,690	1,352

[1] Fish Commission of Oregon cited by Langmo et al. 1975.

[2] 80% of landings.

Table 2. Crab landings and estimated waste production in Oregon.

Port	Landings[1] 1971[3]	Landings[1] 1972-75 Average[3]	Estimated Waste[2] 1971[3]	Estimated Waste[2] 1972-75 Average[3]
	----------thousands of pounds----------			
Astoria and Warrenton	4,643	1,795	2,228	862
Tillamook and Garibaldi	893	298	not processed	
Newport and Depoe Bay	4,520	800	2,169	384
Coos, Winchester, and Siuslaw Bays	2,684	858	1,288	412
Brookings, Gold Beach Port Orford, and Bandon	1,987	400	954	192

[1] Pacific Marine Fish Commission 1976.

[2] 60% of landings are butchered and 80% of butchered crabs is waste.

[3] Landings include December of the previous year.

buying tanner crabs (Chionoecetes sp.) from Alaska, thereby altering the seasonal distribution of crab waste.

Processing

All shrimp processors in Oregon use mechanical peelers. Laitram PCA peelers, in which the shrimp are cooked before peeling, are used in all plants except one (Cheung 1976). After peeling, shrimp pass through washer-cleaners and separators and are inspected before packing. Wastes are suspended in fresh washing, cooking, and cooling waters and consist of shells, antennae, heads, and pieces of meat (U.S. Environmental Protection Agency 1974).

All dungeness crab processing in Oregon is manual. Because of the unpredictable, cyclical nature of the catch, processors are unwilling to invest in expensive equipment (Willis 1976). Crabs to be sold whole in the shell are boiled for 15 to 20 minutes and cooled in fresh water. No solid waste is generated. In processing crab meat, the back, viscera, and gills are removed and the cleaned sections are cooked at approximately 212°F for 10 to 14 minutes. Cooked sections are cooled in water and the meat is manually removed from the shells. Pieces of shell and tendons are removed by floating the meat in a salt brine solution, and the meat is rinsed in fresh water before packing (Willis 1976). Waste consists of back and leg shells, entrails, gills, small pieces of meat, and washing, cooking, and cooling waters (U.S. Environmental Protection Agency 1974).

By July 1, 1977, seafood processors must meet certain waste water quality standards set by the U.S. EPA in accord with the Federal Water Pollution Control Act Amendments of 1972 (U.S. Environmental Protection Agency 1974). These requirements are generally met by passing the liquid and solid wastes over a 40 mesh screen to recover the solids (Thompson 1977. Personal communication). The solid wastes are to be properly disposed of or recovered for by-product utilization. The liquid wastes passing through the screen are moved to the next treatment system, to municipal systems, or more commonly discharged into adjacent bays or estuaries. Many seafood processors in Oregon have installed screens and dispose of shellfish wastes at landfills or make the wastes available to farmers who apply the wastes to their fields. A group of growers in Lincoln County have established the Coastal Farmers Cooperative to distribute shellfish processing wastes. The cooperative has entered into contractual agreements with processors in Newport to remove shellfish waste from the processing plants on a regular basis.

Nature of Shrimp and Crab Processing Wastes

Chemical Composition

Shrimp and crab processing solid wastes consist of shells, viscera, small portions of attached meat, and associated water. The wastes contain nitrogen, phosphorus, calcium, other plant nutrients and non-nutrient elements, and significant amounts of water (Tables 3, 4, and 5).

The N occurs primarily in amino acids and chitin (Kirk et al. 1967). An analysis of shrimp meal for nitrates, pyridine-ring type N, urea, uric acid, and ammonia salts gave only a trace (Kirk et al. 1967). Values determined for estimated actual protein ([total N - chitin N] x 6.25) have been very close to the values determined for amino acid residues (Crawford 1975; Watkins 1977). Using an average of three values given by three researchers (Crawford 1975; Kirk et al. 1967; Watkins 1977), the total N and chitin N for shrimp waste is 6.85% and 1.56% respectively. According to these values, approximately 77% of the total N is contained in amino acids and 23% is contained in chitin.

Phosphorus occurs in the flesh and viscera as well as the shell material. The concentration of P in the shell is

Table 3. Major chemical constituents of shrimp and crab processing wastes.

	Reference	Moisture[1]	Chitin	$CaCO_3$ equiv.[2]	Estimated Actual CP[3]	Amino Acid Residues	Total N	Chitin N	P	K	Ca	Mg	Na
Shrimp		% Fresh Waste	-----------% (dry weight)										
(Pandalus sp.)	1	88	21.04		36.19	30.53	7.23	1.45	2.16	1.65	15.44	0.68	0.23
(Pandalus sp.)	2		19.30		25.54	27.29	5.41	1.33	2.10		14.42		
Shrimp sp.	3		29.7		37.6		7.9	1.9	2.9		11.7		
Shrimp sp.	5		42.3	35.7	22.0								
Crab													
Blue (Callinectes sapidus)	6		13.5		25.0		4.9	0.9	1.8		17.8		
	7		6.97		30.72		5.40	0.48	1.83	1.28	18.68	0.64	1.34
	8						5.25		0.61		24.44	1.61	1.22
Dungeness (Cancer magister)	9	57					5.22						
King (Paralithodes camtschatica)	7		9.14		41.9		7.33	0.63	1.25	0.87	7.24	0.63	3.70
Tanner (Chionoecetes sp.)	5		31.4	57.9	10.7								
Crab sp.	10						5.58		1.74	0.44	17.47		

[1] Calculated as weight of water/weight of wet waste x 100.

[2] Neutralizing value compared to pure $CaCO_3$.

[3] Crude protein corrected for chitin calculated as (Total N - Chitin N) x 6.25.

Table 4. Minor chemical constituents of shrimp and crab processing wastes.

Reference	Ag	Al	B	Ba	Br	Co	Cr	Cu	Fe	Hg	I	Mn	Rb	Sb	Se	Sr	Zn
	ppm (dry weight)																
Shrimp																	
1		345.7	30.8	41.4			27.2	46.7	107.9			12.4				189.6	59.1
4	1.08					0.47	1.07		31.8	1.3			3.2	0.03	5.0		75.0
Crab																	
7 (King)		184.0	23.2	9.4			16.0	116.8	394.7			12.4				200+	264.2
(Blue)		453.0	26.8	35.5				34.1	163.2			400+				200+	106.8
8					333			67			29						
10												191					

Table 5. References and waste sources for shrimp and crab processing wastes.

Reference	Location	Nature of the Waste
1. Crawford 1975	Oregon	Laitram PCA peeler; sweco vibrating screen (40 mesh) solid waste separation; dried in atmospheric double drum dried for analysis.
2. Watkins 1977	Oregon	Laitram PCA peeler; screened to separate solid waste.
3. Kirk *et al*. 1967	Florida	Commercial shrimp meal; processing wastes (minus the head) were steamed and dried.
4. Bertine and Goldberg 1972	Belgium	Shell hand separated from living shrimp.
5. U.S. EPA 1974	Alaska	Shrimp - processing waste Crab - waste from leg and claw shelling
6. Rutledge 1971	Louisiana	Dried commercial crab processing waste.
7. Kifer and Bauersfeld 1969	Alaska	Commercial crab processing wastes; steam cooked, dried at 150° F and ground.
8. Patton *et al*. 1975	Virginia	Commercial crab meal; dried and ground processing wastes.
9. Farragut and Thompson 1966	Washington	All inedible portions of the crab
10. Lubitz *et al*. 1943	South Carolina	Commercial crab meal; steam dried (286° F) and pulverized processing wastes.

higher than that of the fleshy portions. When the relative proportion of shell material was decreased in relation to the fleshy material of blue crab (Callinectes sapidus) waste by drying, grinding, and sieving, the Ca concentration was decreased from 18% to 8% and the P concentration was decreased from 1.8% to 1.5% (Rutledge 1971). Dungeness crab wastes deproteinized with dilute alkali had a P concentration of 2.6% (Laughlin et al. 1973). The P concentration reported for the untreated wastes of several crab species (Table 3) including dungeness ranges from 1.3% to 1.8%. The concentration of P in the fresh meat of queen crab (Chionoecetes opillio), jonah crab (Cancer borealis), and red crab (Geryon quinquedes) ranged from 0.06% to 0.36% on a dry weight basis (Lauer et al. 1974).

Since a large portion of shrimp and crab processing waste is shell material, a closer look at the structure and chemistry of the crustacean exoskeleton is warranted.

Treatment of crab processing waste with dilute alkali to extract protein suitable for animal feed left shell material with a calculated composition of 56.5% $CaCO_3$, 12.8% $Ca_3(PO_4)_2$, and 30.7% chitin (Laughlin et al. 1973).

Chitin is a polysaccaride consisting primarily of unbranched chains of N-acetyl-D-glucosamine units joined by beta 1, 4 linkage, and is found in fungi as well as arthropods where it is the principle component in the exoskeleton. Chitin may be regarded as a derivative of cellulose in which the C-2 hydroxyl groups have been replaced by acetamido residues. The chitin polymer contains 6.89% nitrogen as well as carbon, hydrogen, and oxygen (Merck Index 1976).

Generally one quarter to one half of the dry weight of the anthropod exoskeleton is due to chitin (Richards 1951). Chitin does not occur in the exoskeleton as a distinct and separate chemical entity, but is found in a chitin-protein-mineral complex. The major minerals found in crustacean exoskeletons include calcium, phosphorus, magnesium, aluminum, iron, silicon, and sulfur. Calcium is by far the most common mineral and much of it is present as calcium carbonate as vaterite, calcite, and in an amorphous form. Vaterite is rare, but calcite may occur in either micro or macro crystals. Amorphous calcification may be related to the relative proportion of P to Ca with only a few percent of phosphate ions in the exoskeleton inhibiting the crystallization of calcium carbonate (Richards 1951).

Physical Characteristics

The most important physical property of shrimp and crab wastes as it relates to this study is density. The density of the untreated wastes is an important factor in the handling and transportation of the material. I obtained a value of 626 pounds per cubic yard (0.406 g/cm^3) for untreated shrimp waste that had been frozen. Unpublished information from the New England Fish Company, Newport, Oregon gives the density for fresh shrimp waste as 810 pounds per cubic yard. Dungeness crab waste from Newport, Oregon has an average density of about 350 pounds per cubic yard (Fitzpatrick 1977. Personal communication).

Utilization of Crustacean Processing Wastes

Crustacean processing wastes are used for fertilizer, feed supplements in animal diets, a pigment source for commercially raised salmonids, and feed for commercial shellfish farms. Chitosan, a chitin derivative, has been suggested for use in films, paper, adhesives, water-base paint emulsions, and as a food thickener, gel stabilizer, and water treatment coagulent (Kreag and Smith 1973; U.S. Environmental Protection Agency 1974; Watkins 1977). Regardless of the many potential uses for crustacean processing wastes, only small amounts are being utilized (Jones 1974).

Fertilizer Use

Stevenson (1902) outlines the early fertilizer use of crustacean wastes in America. In 1880, over eight million pounds of horseshoe crabs (Limulus polyphemus) were caught in Delaware Bay for the sole use as fertilizer. They sold for $4 to $8 per ton fresh or $15 to $25 per ton dried and ground or ground and mixed with sulfuric acid. Horseshoe crabs were reportedly an excellent fertilizer for grains and fruits. A desirable grade of fertilizer was made from lobster cannery waste in Maine, Nova Scotia, and New Brunswick. Shrimp processing wastes from Louisiana and California were used to a considerable extent for fertilizer. The dried shrimp shells sold for about $5 per ton and were especially valued in strawberry and vegetable culture. For strawberries, applications of 300 to 400 pounds per acre of dry wastes were common. Turrentine (1913) reports that a fertilizer mixing plant in Chesapeake Bay used over 250 tons of crab shells annually.

The importance of organic materials as nitrogen sources rapidly declined as inorganic sources became available. By 1900 ammonium sulfate and nitrate of soda were becoming available and supplied nitrogen at a lower cost than organic sources. By 1930 inorganic nitrogen was less than half the price of organic nitrogen (Ibach and Mahan 1968).

As the demand for crustacean wastes declined, processors commonly discarded their wastes into adjacent waters. Subsequent attempts to utilize crustacean processing wastes have been aimed at reducing pollution or disposal problems.

In Alaska, dungeness crab processing wastes were treated with dilute alkali to extract protein suitable for animal feed. The remaining shell material was found to contain 2.9% water, 2.1% N, 2.6% P, 30.7% chitin, and 58.2% calcium carbonate equivalent. The shell material was mixed at five application rates (1, 2, 3, 4 and 5 tons per acre) with two acid soils (pH 4.26 and pH 4.63) in the greenhouse. Four size fractions (original, passing 10-mesh, 50-mesh, and 100-mesh screens) of shell material were used. Romaine lettuce was grown as the indicator crop. Increasing shell application rates decreased soil acidity, however, no significant differences among size fractions occurred after the second month. After two months, 5 tons per acre of treated crab shell increased the pH from 4.4 to 5.2. Applications up to 3 tons per acre increased the extractable P. Applications of treated crab shell increased yields of romaine lettuce (Laughlin *et al.* 1973).

Chitin in the Soil

Decomposition

Chitin is practically insoluble in water, dilute acids, dilute and concentrated alkalies, alcohol, and other organic solvents

(Merck Index 1976), was found to have little or no protein value for rats and chicks (Lubitz et al. 1943), and has a low solubility in the rumen of fistulated steers (Patton and Chandler 1975). Chitin decomposing microorganisms are common. Bacteria, both aerobic and anaerobic, capable of decomposing chitin have been found in nearly every habitat in which they have been sought including fresh water, salt beds, sea water, guts of marine, fresh water, and terrestrial animals, mud, soil, and decomposing manure (Richards 1951). Since chitin is a component of many soil organisms including fungi, green algae, annelids, arthropods, nematodes, and the cysts and testae of certain protozoa, the soil must contain significant quantities of chitin (Okafor 1966a). Because chitin contains 6.89% nitrogen, breakdown is not limited by lack of nitrogen. The products of decomposition are glucose and ammonia (Gray and Williams 1971).

Fungi, bacteria, and actinomycetes attack chitin. The most common forms are species of *Mortierella*, *Pseudomonas*, *Bacillus*, and *Streptomyces* (Gray and Baxby 1968; Okafor 1966b). Actinomycetes are prominent chitin decomposers in agricultural soils (Veldkamp 1955, cited by Gray and Williams 1971). The dominant group of microorganisms and the actual species present are influenced by soil temperature (Okafor 1966a) and soil reaction (Gray and Baxby 1968).

Bremner and Shaw (1954) incubated purified chitin with moist soil at 25°C for 70 days and recovered 48% of the added chitin-N as NO_3. Okafor (1966c) incubated purified chitin with moist soil and measured the release of about 55% of the carbon in the first 20 days and about 66% of the carbon after 100 days.

Conditions favorable for general microbiological activity will favor chitin breakdown in the soil. One of the principle factors governing the rate of chitin decomposition in the soil is the nature of the substances associated with it (Gray and Williams 1971). Untreated insect wings were recovered from the soil after 300 days whereas all deproteinized wings (shown to consist mainly of chitin) had disappeared after 200 days. The resistance to decomposition was suggested to result from the thick wax layer of the epicuticle and possibly components of the pro-cuticle (Okafor 1966b). Crustacean exoskeletons are not likely to exhibit this resistance to decomposition in the soil because the outer protective layers are not as thick as those on insect exoskeletons and wings (Richards 1951) and the unprotected inner surface of the exoskeleton is exposed. Since naturally occurring chitinous materials are complex substances, decomposition is brought about through the cooperation of several organisms (Crasemann 1954; Okafor 1966b).

Plant Disease Control

Applications of 225 to more than 1200 kg of unbleached, purified chitin/ha mixed with the soil at or just prior to planting have significantly reduced the severity of several fungal diseases. Chitin applications have reduced the severity of pea wilt caused by *Fusarium oxysporum* f. *pisi* (Buxton *et al*. 1965; Khalifa 1965), vascular wilt of radishes caused by *Fusarium oxysporum* f. *conglutinans* (Mitchell and Alexander 1961), root-rot of beans caused by *Fusarium solani* f. *phaseoli* (Mitchell and Alexander 1961, 1962) and damping off caused by *Rhizoctonia solani* (Sneh *et al*. 1971, 1972). The addition of 300 to 900 kg of ground lobster shell/ha (12-20% chitin) significantly decreased the severity of root-rot caused by *Fusarium solani* f. *phaseoli*, but 3600 kg of lobster shell/ha increased the severity (Mitchell 1963). It has been suggested that chitin applications stimulate actinomycetes that produce toxins or other substances active against the disease producing soil fungi (Buxton *et al*. 1965; Mitchell 1963; Mitchell and Alexander 1961, 1962; Sneh *et al*. 1972). Most workers report a reduction in the severity of certain fungal diseases as a result of chitin amendment, but a lack of response as well as increased disease severity have also been reported (Gindrat 1976; Okafor 1970; Sneh *et al*. 1971).

Fertilizer Nitrogen

Grass Yield and Plant Composition

The supply of N is a major limiting factor in the growth of grasses. The addition of fertilizer N to an N deficient soil often results in large increases in grass yield and significant changes in plant chemical composition. The ultimate measure of the value of any agronomic input into the soil-plant-animal system is animal productivity.

There is a large volume of literature reporting increases in grass yield with added fertilizer N. Ward (1959) cites many experiments in which N applications have increased grass yield and concludes that the response of forage crops to fertilization varies with the soil type, relative level of fertility within soil type, ratio of available nutrients, crop, and climatic conditions. Water availability plays an important role in plant response to added plant nutrients (Tisdale and Nelson 1975).

With cool-season grasses, yields have been increased with N rates up to approximately 560 kg/ha. Higher rates have generally reduced yields (Donohue et al. 1973; George et al. 1973; Schmidt and Tenpas 1965). Whitehead (1970) states that in temperate regions, grass yield is generally proportional to the supply of N up to rates of 340 to 500 kg/ha per year.

Total plant N generally increases with N application. In a study with three cool-season grasses, George et al. (1973) found that increasing rates of N over the range of 0 to 1,344 kg/ha per year increased the total-N in the forages for all species. The total-N percentage for orchardgrass (Dactylis glomerata L.) was 2.36 and 4.08 for 0 and 1,344 kg N/ha per year respectively.

Generally most of the N in forages exists in protein and non-protein organic forms such as amino acids and peptides, with smaller amounts of a wide range of compounds such as purines, betaine, and choline (Whitehead 1970). Increases in N concentrations other than NO_3-N in forages represent a net improvement in quality because of the ability of the ruminant animal to synthesize protein from low quality plant protein and non-protein plant N.

Under certain environmental conditions and with high rates of N fertilizer, potentially toxic levels of NO_3-N can accumulate in plants. The effect of N fertilization on NO_3-N accumulation and the effects of NO_3-N in forage on the ruminant animal will be discussed in another section.

Some general trends have been reported for the effect of N fertilization on the mineral composition of forage plants. Reid et al. (1970) working with five grass species reported that with an adequate K supply, increasing rates of fertilizer N of O to

500 kg/ha per year consistently increased the K concentration of the forage and slightly decreased the P concentration. The effect of N fertilization on the Ca and Mg concentrations was not consistent but frequently the concentration of these elements increased with N fertilizer application. They reported a steady decline in the concentration of most of the major elements with maturity. Some trends are evident, but conflicting data exists. The mineral composition of forage plants is influenced by a number of factors including species, stage of growth, plant part, soil pH and fertility, and fertilizer applications (Sullivan 1969).

Nitrogen Fertilization and the Ruminant Animal

Forage based animal production depends upon forage intake, digestability, and quality, as well as total forage production.

Conflicting reports have been published concerning the effect of N fertilization on the intake of forages, but most experiments under *ad libitum* feeding have shown no differences in voluntary intake of grasses grown under widely different levels of N fertilization (Raymond 1969). An exception occurs in the case of forages of very low crude protein content. Intake of pangola grass (*Digitaria decumbens* Stent.) was 54% higher with 517 kg urea/ha (7.2% crude protein) than with 247 kg of urea/ha (3.7% crude protein) (Minson 1967). Forages with low crude protein are likely deficient in N for optimal rumen activity when used as the sole feed (Waldo 1968).

The major factor limiting the intake of forage by the ruminant animal is the capacity of the rumen and digestive tract. The more digestible the forage and the faster it passes through the digestive system, the more the ruminant can eat (Balch and Campling 1962).

Nitrogen fertilization of grass forage does not have a consistent effect on digestibility. Waite (1970) reports that with applications of 27 and 107 kg N/ha per year on ryegrass and orchardgrass, the higher rate of N allowed more frequent harvests of grass with lower pectin, cellulose, and hemicellulose and hence a higher level of digestibility. Other workers have found no significant change in digestibility of grasses fertilized with N (Blaxter et al. 1971; Niehaus 1971).

Although output per animal is not generally improved by N fertilization of grasses, large increases in carrying capacity and livestock products per hectare are made possible as a result of increased yield of grass forage (Blaser 1964). In a four year study on tall fescue (Festuca arundinacea Schreb.) pasture, N fertilization slightly (but not significantly) depressed the average daily gain of yearling steers, but nearly doubled the carrying capacity of the pasture and greatly increased liveweight gain per hectare (Mott et al. 1971). Blaxter et al. (1971) fertilized a ryegrass sward with

248, 532, and 589 kg N/ha per year and studied the effects on animal production. The data from calorimetric trials showed no differences in nutritive value of the grass as a result of N fertilization. They concluded from the results of calorimetric and appetite experiments that the effect of N fertilization of grass on animal production per unit of land is simply proportional to the increase in yield of dry matter.

A variety of metabolic disorders in ruminants have been attributed to N fertilization.

Using balanced rations in feeding programs may solve many of the problems ascribed to N fertilization. The consumption of N fertilized grasses as the sole ration may result in a diet in which the N intake is much higher than the required intake of available carbohydrates. This circumstance would result not only in the wastage of the excess N, but could also lead to high levels of nitrogenous compounds in the rumen with possible adverse effects on the animal (Noller and Rhykerd 1974). The need to balance high crude protein grass forage with an energy supplement is indicated.

Some work has linked N fertilization of grasses to hypomagnesemia. Kemp et al. (1966) reported that an increase in forage crude protein from 10% to 30% was associated with an increase in higher fatty acids and a decreased availability of dietary Mg to the ruminant animal.

Some controversy exists on what may be a toxic level of nitrate in forage. Recent publications cite 0.15% NO_3-N as the upper safe level (George et al. 1973; Ryan et al. 1972), although classical symptoms of nitrate poisoning seldom occur until the diet contains in excess of 0.35% to 0.45% NO_3-N (Wright and Davison 1964).

In a two year study on the effect of split N applications ranging from 0 to 1,344 kg/ha per year on the NO_3-N accumulation of three cool-season grasses, George et al. (1973) found NO_3-N concentrations often exceeded 0.15% with N rates greater than 672 kg/ha per year (4 applications of 168 kg/ha). Concentrations of NO_3-N in excess of 0.15% were found at the 336 kg N/ha per year rate (4 applications of 84 kg/ha) only with mid-summer harvest of orchardgrass (Dactylis glomerata L.) following three months of below normal precipitation. George et al. (1973) suggest that when nitrogen is applied at rates necessary for maximum forage dry matter yield, the risk of nitrate toxicity problems is minimal with the possible exception of forage grazed or harvested during or following periods of below normal precipitation.

Grass-Legume Associations

Grass-legume associations are the basis of forage production in the temperate regions of the world. The use of nitrogen fertilizer in forage production must be considered in this context.

There are numerous reports in the literature of grass stimulation and clover suppression resulting from N fertilization of grass-clover associations (Frame 1973; Garder *et al.* 1960; Templeton and Taylor 1966). Often, this change in botanical composition can be modified by clipping or grazing. In a four year study, a Kentucky bluegrass-white clover (*Trifolium repens* L.) sward received split applications of 300 to 400 kg N/ha per year and was clipped when growth reached 10 cm. Very little clover remained on plots clipped to 5 cm, but fair stands of clover (about 20%) remained on plots clipped to 2.5 cm (Robinson *et al.* 1952).

The effects of N application, clipping, and grazing on the proportion of clover in grass-clover associations are all largely accountable as the direct and indirect effects of the shading of the clover by taller grasses (Donald 1963, Stern and Donald 1962). Nitrogen status and light relationships govern the competitive pattern of most of the world's grass-clover pastures, however, other factors including the status of nutrients such as potassium, sulfur, phosphorus, or molybdenum are important (Donald 1963).

Competition for K between grass and clover grown in association was recognized by Blaser and Brady (1950). Nitrogen fertilization intensified the competition by stimulating grass growth and increasing uptake of K by the grass. They attributed a reduction in the leguminous associate to competition for K. Drake et al. (1951) report that with grass-legume associations growing under low levels of soil K, grasses are able to take up more K than legumes because of the much lower cation exchange capacity of the grass root surface. As a result, at low levels of soil K, legume yields and longevity of stands are seriously reduced.

Fertilizer application and rhizobial activity cannot be considered as additive sources of N. In general, applied N will reduce rhizobial N until displacement is complete and fertilizer N must be further increased to give a net improvement in the N supply (Donald 1963; Linehan and Lowe 1960; McAuliffe et al. 1958).

In a number of experiments, the rates of N required annually on pure grass swards to equal forage yields on grass-clover swards receiving no N ranged from 140 to 200 kg/ha on a dry weight basis, and from 220 to 300 kg/ha on a crude protein basis (Cowling 1961; Reid 1972; Whitehead 1970). Higher required rates have been reported from New Zealand (Weeda 1970).

The economic feasibility of applying N to grass-legume associations has been the subject of much research. The use of additional N on grass-legume associations requires careful management to maintain a desirable grass-legume balance. Some workers have suggested that except for special purposes and under skillful management, fertilizer N should not be applied to grass-legume associations since extra yields of grass are usually accompanied by depression of legumes (Doll _et al._ 1961; Linehan and Lowe 1960; Walker 1962).

Kresge (1964) reports that yield increases can be obtained from N fertilization of grass-legume associations, but the economics should be carefully evaluated if the percent legume exceeds 25 and weighed against the disadvantage of a probable decrease of the legume component. Kresge (1964) suggests that associations with less than 20% to 25% legume should be treated as pure grass stands in relation to N fertilization.

On irrigated grass-clover pastures in western Oregon, applications of 34 to 45 kg N/ha are suggested in late February or early March to stimulate grass growth and provide early feed, and again in late August to stimulate grass growth and provide additional fall grazing. Summer N applications are not recommended if the legume component is adequate (Gardner _et al._ 1971).

Groundwater Pollution

Nitrogen in plant and animal residues and various forms of N fertilizers applied to the soil are changed to the nitrate form by nitrifying bacteria under soil conditions favorable for crop growth. Since nitrate is highly soluble and not held on the clay complex in the soil, leaching losses can be significant. Except where considerable runoff occurs, nitrate is usually low in surface runoff

(Jackson et al. 1973; Moe et al. 1967), but significant levels of nitrate have been reported in drainage waters from N fertilized fields (Kohl et al. 1971; Zwerman et al. 1972) and in groundwaters in areas of agricultural activity (Stewart et al. 1967; Taylor and Bigbe 1973).

Nitrate pollution of groundwater occurs when both available N exceeds withdrawal by the crop and percolation occurs (Secretary of Agriculture and Director of the Office of Science and Technology 1969). Measures to avoid or control nitrate contamination of groundwaters include reducing the applied N to amounts close to those actually taken-up by a crop and avoiding applications of fertilizer N in months when crop uptake is low and deep seepage of water is high (Department of Agronomy, Cornell University 1971).

October N applications of 112 kg/ha on annual grass and grass-clover mixtures in California resulted in a 41% to 65% increase in nitrate in drainage waters over the control in November and December. Of the N leached, 94% was in the fall, 6% in the winter, and 0.1% in the spring. Of the N applied, 38% to 50% was unaccounted for by crop uptake or leaching and most of this N loss was attributed to denitrification during the wet winter (Jones et al. 1974).

To minimize nitrate contamination of groundwater, it is important to determine those rates of applied N that provide

satisfactory yields and result in the greatest recovery of applied N by the crop. Over a three-year period in Indiana, maximum orchardgrass (Dactylis glomerata L.) yields on a silt loam soil were obtained by an average N rate of 336 kg/ha/yr (four equal increments during the growing season). The rate at which the nitrate pollution potential was minimal (where N application equaled N removal) was 247 kg N/ha/yr over a five-year period.
For optimum orchardgrass yield with minimal N leaching loss under the climatic conditions of central Indiana, an N rate of 250 kg/ha/yr was recommended (Donohue et al. 1973).

Fertilizer Phosphorus and Forage Production

Phosphorus is a necessary component of every living plant and animal cell. Phosphorus is probably the most commonly deficient nutrient for optimum forage growth (Baylor 1974) as well as the most critical mineral deficiency in grazing livestock (Allaway 1975).

Crop yield response to P fertilization depends upon the level of available P in the soil (Ward 1959). On nine Saskatchewan soils with a pH range of 7.1 to 7.9, a P response from a bromegrass-alfalfa mixture was obtained on soils with less than 10 ppm bicarbonate extractable P, but not on soils with more than 20 ppm (Read 1966). For the acid soils of western Oregon, P fertilization is recommended on irrigated grass-clover pastures if dilute acid-fluoride extractable soil P (Bray method) is less than 30 ppm (Gardner et al. 1971). In 1975, a total of 195 soil samples from Oregon coastal counties were analyzed for P in the Oregon State University soil testing laboratory. Of the samples analyzed, 77% had extractable soil P values (Bray method) of less than 20 ppm (Oregon State University Soil Testing Laboratory 1975). Obviously P deficiencies are common in Oregon coastal soils.

Because P stimulates seedling growth and increases seedling vigor, liberal applications of P for establishing new seedings are justified (Baylor 1974).

The usual response from P applications to an established grass-clover association on a P deficient soil is an increase in total yield as well as an increase in the clover component (Baylor 1974).

With the aid of P^{32} on an orchard grass-ladino clover association, Blaser and McAuliffe (1949) reported differences in fertilizer and soil P uptake between the associated species. They found that orchardgrass absorbed the less available soil P more efficiently than did ladino clover and suggested that P fertilization is important for seedling establishment for both species and for maintenance of ladino clover.

In a study on grass-clover pastures on phosphorus deficient soils in three counties in California, applications of 39 kg P/ha increased clover yields in every instance. This was accompanied by increases in grass growth presumably due to increased N fixation by the stimulated clover (Martin _et al._ 1965).

A yield increase of 50% was measured from a single P application of 197 kg/ha on an irrigated ladino clover-orchardgrass pasture on a soil with low available P in Virginia. The % P in the forage in relation to P treatment was 0.18 and 0.29 in orchardgrass and 0.17 and 0.27 in ladino clover for no P and 197 kg P/ha respectively (Lütz _et al._ 1962).

The P content of forages ranges from about 0.14% to 0.50% and is influenced by soil fertility more than any other factor. The P concentration in grasses and legumes is similar when grown under the same environmental conditions. When forage is the only feed for grazing animals, the P concentration is an important factor in feed quality (Sullivan 1969). The P concentration of both orchardgrass and alfalfa generally decreases with maturity (Reid _et al._ 1970).

Recovery of applied fertilizer P by crop plants is usually less than 24% in the year of application, and maximum yields can be obtained only by supplying much more P than the plants can absorb in a given season (Krantz _et al._ 1949; Martin _et al._ 1965).

Applications of P fertilizers can result in a build-up of soil P levels. On an alfalfa-orchardgrass association in Virginia, soil test values for available P were about four times higher on plots receiving annual applications of 98 kg P/ha than on plots that received a single application of 98 kg/ha when measured after four years. In terms of forage yield, 25 kg P/ha applied annually was the most practical rate, and even at this rate, available soil P was three times higher after four years than on the plots where no P was applied (Sears and Blaser 1957). A major portion of fertilizer P is reverted to less available forms. The reverted P is not lost and is undoubtedly slowly available to growing plants over the years, especially in soils which have received heavy applications of P fertilizers (Brady 1974).

In acid soils, added P reacts with Fe and Al compounds to form complex products that are less available to plants due to low solubilities. On such soils, the use of lime is necessary to ensure more efficient utilization of added P fertilizers. A soil pH range of about 5.5 to 7.0 is generally considered the most favorable for P availability, with the upper part of the range preferable when other crop production factors are considered (Phillips and Webb 1971).

Lime in Relation to Forage Production

From a total of 200 soil samples from the coastal counties of Oregon analyzed in the Soil Testing Laboratory at Oregon State University in 1975, 53% had a pH value less than 5.5 (Oregon State

University Soil Testing Laboratory 1975). Except for acid tolerant crops, the need for lime on coastal soils of Oregon is indicated.

High acidity is detrimental to plant growth as a result of one or more of the following:

1. increased solubility of toxic elements, especially Al and Mn,
2. decreased availability of essential nutrient elements, especially P and Mo, and
3. repressed activity of desirable soil microorganisms, most notably in the case of legumes, the N_2-fixing bacteria of the genus Rhizobium (Pearson and Hoveland 1974).

Forage grasses, however, are generally tolerant of acid soil. Low forage yield is often a result of nutrient deficiencies not related to low soil pH (Pearson and Hoveland 1974). Soluble Al and Mn levels vary among soils at the same pH and may cause wide differences in plant response to lime (Elliot et al. 1973). Significant differences can be found between cultivars or genotypes of grasses in their tolerance to soil acidity (Vose 1963). Cool-season grasses are commonly grown in association with legumes which generally require a higher soil pH, hence the liming program is directed at the legume rather than the grass (Pearson and Hoveland 1974).

During and Rolt (1967) reported that optimum yield of a white clover-grass pasture was not reached until the soil was limed to at least pH 6.0. Optimum yields of white clover (Trifolium repens L.) are more commonly obtained by liming to about pH 5.8 (Gammon and Blue 1968; Sanford et al. 1968). Subterranean clover (Trifolium subterraneum L.) is relatively tolerant of acid soils (Pearson and Hoveland 1974).

Soil acidity affects legume growth and symbiotic nitrogen fixation in a number of ways. Restricted root growth of alfalfa (Medicago sativa L.) growing in acid soils has been attributed to Al toxicity, and the total yield of nitrogen from an alfalfa stand was increased by a factor of approximately 200 when 6 T/A of lime was applied to a soil with an untreated pH of 5.0 (Kauffman 1976). In South Africa, nodulation of white clover (Trifolium repens L) was limited at pH 4.8 but satisfactory at pH 5.4. The clover rhizobia survived and multiplied at pH 4.8, possibly indicating that a higher pH is required for the root hair infection stage (Loos and Louw 1965). With alfalfa (Medicago sativa L.) grown in nutrient solutions, acidity reduced nodule numbers at pH less than 5.5 and virtually prevented nodulation at pH 4.4. Large rhizosphere populations of Rhizobium accumulated at pH 4.4 but root hairs did not curl and become infected. Raising the pH from 4.4 to 5.4 resulted in curling and nodulation (Munns 1968).

The detrimental effects of H^+ ions on nodulation can be overcome to some extent by increasing the Ca concentration (Loneragan and Dowling 1958). Infection of the root hair by Rhizobium has a much higher Ca requirement than nodule development or growth of the plant (Kamprath and Foy 1971).

Lime pelleting of subterranean clover has been shown to be effective in overcoming the detrimental effects of soil acidity. In Australia with subterranean clover sown on a soil with pH 5.2, approximately 5 kg of lime/ha pelleted with the seed was as effective as 250 kg of lime/ha banded with the seed. Both treatments increased forage yields by more than a factor of 4 over the no lime treatment. Stand and percentage of plants nodulated were similar for both treatments (Loneragan et al. 1955).

An adequate supply of Mo is essential in the symbiotic N fixation process in legumes (Griffith 1974). Liming acid soils increases the availability of Mo, and the application of either lime or Mo to acid soils has increased legume yields (James et al. 1968).

GREENHOUSE EXPERIMENTS

Experiment I

Introduction

Little information is available on the behavior of crustacean processing wastes in the soil and their effects on crop plants.

The purpose of this experiment was to determine the general fertilizer value of shrimp and crab processing wastes, and the best ways to apply the wastes to the soil, by measuring the effects of:

1. surface vs. mixed (soil incorporated) waste applications,
2. grinding the waste material, and
3. shrimp and crab waste applications vs. inorganic fertilizer-lime applications at equivalent N rates with other recommended major nutrients supplied to the inorganic fertilizer treatments only.

Each of these effects was measured on two pasture crops, on two coastal soils in the greenhouse by determining one or more of the following:

1. forage yield,
2. phosphorus concentration in grass and clover,
3. nitrogen concentration in grass,

4. nitrogen uptake by grass, and

5. soil chemical composition.

Materials and Methods

Treatments

Shrimp waste, crab waste, and inorganic N were applied to the soil at rates equivalent to 56, 168, and 336 kg N/ha (Table 6, Figure 5). Ground limestone and inorganic sources of P and S were applied to the soil with the inorganic N but not with the processing wastes (Table 7). Applications are on a weight basis, assuming one hectare of soil weighs 2,242,000 kg. Nutrient needs and application rates (other than N) were determined by soil analyses (Table 11) and fertilizer recommendations (Department of Soil Science 1972; Gardner *et al.* 1971).

Treatments (Table 8) were replicated three times and the pots were arranged on the greenhouse benches in a randomized complete block design.

Shrimp and Crab Waste Materials

Shrimp and crab processing wastes were obtained from the New England Fish Company, Newport, Oregon.

Shrimp solid waste was separated from the waste flow of a

Table 6. Shrimp and crab waste application rates.

	Shrimp			Crab		
	Waste Applications					
g/pot[1]	0.95	2.84	5.68	1.23	3.69	7.38
kg/ha[2]	4,400	13,200	24,400	3,482	10,446	20,892
tons/acre[2]	1.96	5.88	11.76	1.55	4.65	9.30
	Nutrients Supplied kg/ha					
Nitrogen	56	168	336	56	168	336
Phosphorus	19.0	56.7	113.4	18.7	56.0	112.1
Potassium	1.1	3.2	6.4	4.5	13.5	27.1
Magnesium	7.6	22.9	45.7	11.5	34.6	69.2
Sulfur	2.7	8.1	16.2	6.5	19.6	39.1
Liming Value[3]	284	848	1,696	521	1,564	3,129

[1] Oven dry (60°C).

[2] Shrimp at 78% moisture and crab at 64% moisture.

[3] $CaCO_3$ equivalent = 100 (Table 12).

--------kg N/ha----------

56 168 336

Top row, shrimp waste, unground (1.27 cm)

Bottom row, crab waste (1.27 cm)

Figure 5. Shrimp and crab waste surface applications.

Table 7. Inorganic nutrient and lime applications.

Nutrient	Source[1]	Soil: Knappa	Soil: Nehalem
		------------kg/ha	-------------
Nitrogen	NH_4NO_3	----[2]	----[2]
Phosphorus	$NH_4H_2PO_4$	44.8	39.2
Sulfur	$CaSO_4$	22.4	22.4
Boron	H_3BO_3	3.4	3.4
Limestone[3]	----	11,210[4]	2,242[5]

[1] Reagent grade.

[2] 56, 168, and 336 Kg N/ha for each soil.

[3] Finely ground, $CaCO_3$ equivalent = 95 (Table 12).

[4] Rate recommended to raise the pH to 5.6.

[5] Rate recommended to raise the pH to 6.0.

Table 8. Treatments and assigned treatment numbers.

Material	Size Fraction (cm)	N Rate (kg/ha)	Treatment Numbers: Knappa Soil: Grass: Mixed[2]	Surface[2]	Association[1]: Mixed	Surface	Nehalem Soil: Grass: Mixed	Surface	Association[1]: Mixed	Surface
Shrimp waste	1.27	56	5	6	7	8	1	2	3	4
	(unground)	168	13	14	15	16	9	10	11	12
		336	21	22	23	24	17	18	19	20
	0.32	56	37	38	39	40				
		168	41	42	43	44				
		336	45	46	47	48				
Crab waste	2.54	56	49	50	51	52				
		168	53	54	55	56				
		336	57	58	59	60				
	1.27	56	61	62	63	64	65	66	67	68
		168	69	70	71	72	73	74	75	76
		336	77	78	79	80	81	82	83	84
	0.32	56	85	86	87	88				
		168	89	90	91	92				
		336	93	94	95	96				
Inorganic-Lime		56	109		111		105		107	
			110		112		106		108	
		168	117		119		113		115	
			118		120		114		116	
		336	125		127		121		123	
			126		128		122		124	
Control		0	101		103		97		99	
		0	102		104		98		100	

[1] Grass-clover association.

[2] Application method.

Laitram PCA mechanical peeler by a hand held 40-mesh screen. The wastes were spread and air dried in the greenhouse, and a subsample was assayed (Table 9). Two size fractions of shrimp waste were used. Dry shrimp waste was passed through a sieve with square holes, 1.27 cm on a side (unground). Additional dried shrimp waste was chopped in a blender until the waste passed a sieve with square holes, 0.32 cm on a side.

Dungeness crab waste consisted of backs, entrails, and leg shells which were left after the meat was hand picked at the processing plant. The waste remained frozen until oven dried at 65° C. Three size fractions of crab were used. Random portions of the waste were wrapped in a towel and broken by hand until they passed sieves with square holes, 2.54 cm on a side for the largest size fraction, and 1.27 cm on a side for the medium size fraction. Additional random portions of the waste were chopped in a blender until the waste passed a sieve with square holes, 0.32 cm on a side.

Soils

Two coastal soils were used (Table 10). The Knappa silt loam belongs to the fine-silty, mixed, mesic family of the Pachic Haplumbrepts. It consists of well-drained, deep, nearly level to strongly sloping soils found on terraces along foothills. The

Table 9. Chemical composition of shrimp (Pandalus jordani) and dungeness crab (Cancer magister) processing wastes.[1]

Waste	N	P	K	Ca	Mg	S	Na	$CaCO_3$ Equivalent	B	Moisture
	--------% dry weight--------								ppm dry weight	% of fresh weight
Shrimp										
Greenhouse I	5.81	1.96	0.11	15.4	0.79	0.28	0.47	29.3	50.1	77
Greenhouse II and Field Experiment	5.83	2.15	----	----	----	----	----	----	----	78
Crab	4.47	1.49	0.36	19.4	0.92	0.52	1.40	41.6	46.5	64
	--------pounds/ton fresh waste[2]--------									
Shrimp	25.6	8.6	0.5	67.8	3.5	1.2	2.1	129	.02	1540
Crab	32.2	10.7	2.6	139.7	6.6	3.7	10.1	300	.03	1280

[1] Analyses were performed by the Soil Testing Laboratory, Oregon State University (Table 12) .

[2] 78% and 64% moisture for shrimp and crab wastes respectively.

Table 10. Soil chemical analysis of Knappa and Nehalem silt loams.[1]

	pH	SMP	P	K	B	Ca	Mg	Total-N	OM
			--------ppm--------			-meq/100g-		--------%--------	
Knappa	5.0	5.0	12	210	0.31	1.9	0.96	0.43	12.0
Nehalem	5.8	6.4	16	236	0.29	8.5	3.4	0.16	4.5

[1] Soil analyses by methods outlined in Table 11.

Knappa soil was obtained from a nearly level, partially cleared native pasture in Lincoln County (sec. 14, T.13S., R.11W.). The Nehalem silt loam belongs to the fine-silty, mixed, mesic family of the Fluventic Haplumbrepts. It consists of well-drained, very deep, nearly level to gently sloping soils that occupy a large acreage of bottom lands. The Nehalem soil was obtained from an improved pasture in Coos County (sec. 15, T.28S., R.12W.). Both soils are used primarily for pasture and forage crops.

The soils were removed to a depth of 15 to 20 cm, air dried in the greenhouse, and passed through a sieve with square holes 1.27 cm on a side.

Crops

Two pasture crops were grown:

1. a pure stand of orchardgrass (*Dactylis glomerata* L.) 'Potomac', and
2. an association of orchardgrass and New Zealand white clover (*Trifolium repens* L.).

Orchardgrass and inoculated white clover were seeded in excess. After germination, the plants were thinned to 12 per pot, with six grass and six clover in the association.

Procedure

Air dry soil (2.2 kg) was weighed into plastic pots with a bottom drainage hole. Inorganic nutrients (except N) and lime, or processing waste, was mixed in a twin-shell dry blender with the soil from the appropriate pots designated as inorganic fertilizer or mixed processing waste treatments. Orchardgrass and white clover were seeded and the soil was brought to near field capacity with distilled water on September 26, 1975. Separately, in solution, an equivalent of 3.4 kg B/ha (as H_3BO_3) was added to all pots, and N was added to those pots designated as inorganic fertilizer treatments. Immediately following germination, the shrimp and crab wastes were applied to the soil surface in those pots designated for surface treatments. The plants were clipped to a height of 1.5 cm every seven weeks. The orchardgrass was harvested four times and the grass-clover association was harvested six times with total growing periods of 196 and 294 days respectively. Grass and clover plant material was separated when clipped. The harvested plant material was oven dried at 65°C for two to three days and weighed. Plant samples were ground in a wiley mill and selected samples were assayed for N and P concentrations (Table 12).

Table 11. Methods of soil analysis.[1]

Soil Test	Method[2]	Reference
B	hot water soluble, curcumin	Dibble *et al.* 1954
pH	1:2 soil to water ratio	Jackson 1958
Lime requirement	SMP buffer pH	Shoemaker *et al.* 1961
P	dilute acid-flouride extractable (ammonium vanadate-ammonium molybdate color forming reagent)	Bray and Kurtz 1945; Jackson 1958
K, Ca, Mg	atomic absorption, ammonium acetate extractable	Pratt 1965
NO_3-N, Total-N	steam distillation micro-Kjeldahl	Bremner 1965
Organic matter	Walkley-Black titration	Walkley and Black 1934
SO_4-S	1N KCl extractable, methylene blue	Johnson and Nishita 1952
Total soluble salts	Electrical conductivity	Richards 1954

[1] Soil analyses were performed by the Soil Testing Laboratory, Oregon State University.

[2] Kauffman and Gardner 1976.

Table 12. Methods of plant and waste analysis.

Analysis	Method	Reference
Total-N	micro-Kjeldahl (to include NO_3)	Jackson 1958
B	dry ash, curcumin	Dibble _et al_. 1954
$CaCO_3$ equivalent	neutralization	Association of Official Agricultural Chemists 1945
Total-S	nitric acid-perchloric acid digest; methylene blue color forming reagent	Johnson and Nishita 1952
P	nitric acid-perchloric acid digest; vanadate-molybdate color forming reagent	Jackson 1958
Ca	nitric acid-perchloric acid digest; atomic absorption	----
Mg	nitric acid-perchloric acid digest; atomic absorption	----
K	nitric acid-perchloric acid digest; atomic absorption	----
Na	nitric acid-perchloric acid digest; atomic absorption	----

Greenhouse Conditions

Thermostats were set at day and night temperatures of 18°C and 15° C respectively. The temperature seldom went below the minimum, but during the summer months the maximum temperature was often exceeded. Temperatures occasionally reached 30° C on summer afternoons. Distilled water was added on one to three day intervals as needed to provide adequate soil moisture. Drainage water was recycled. Supplemental flourescent lighting was supplied during the day on a 12 hour period from October to May. The lights were kept at a height of 10 to 40 cm above the top of the plants and the flourescent tubes were spaced every 15 cm.

Statistical Analysis

The treatments were arranged into nine factorial arrangements for the analyses of variance. Because shrimp and crab processing wastes will be used over a wide variety of conditions, all available factors were included in each factorial arrangement. In the results of the analyses of variance, only main effects of interest and their first-order interactions are presented. A table of means (averaged over replications only) is presented for all factorial arrangements so all interaction means can be easily calculated. Control values were not included in the analyses of variance. In all analysis of variance tables, the following symbols signify; ** significance at the 1% level of probability, * significance at the 5% level of probability, and NS no significance at the 5% level of probability. The LSD and $S_{\bar{x}}$ are presented when appropriate.

Regression and correlation techniques were used to define numerical relationships between applications of shrimp and crab wastes and subsequent plant and soil characteristics.

Except when indicated, cumulative forage yields are reported. All data are listed in Appendix Tables 1-5.

Results and Discussion

Effect of Waste Application Method

The purpose of the first factorial analysis was to characterize the experimental materials as well as to determine the effect of waste application method (mixed vs. surface) on forage yield (Tables 13 and 14). It is important to understand the growth characteristics of the two crops on each soil in order to interpret the interactions of these factors with the fertilizer materials.

With applications of processing wastes on two coastal soils, grass yields were slightly higher on the Knappa soil, but the grass-clover association yields were substantially higher on the Nehalem soil than on the Knappa soil (Table 13, Figure 6). The difference

Table 13. Effect of application method on forage yield.[1]

Fertilizer	N rate	Knappa Soil				Nehalem Soil			
		Grass		Association		Grass		Association	
		Mixed	Surface	Mixed	Surface	Mixed	Surface	Mixed	Surface
	kg/ha	g/pot							
Shrimp[2] waste	56	7.48	5.56	10.04	6.53	5.12	4.30	25.62	26.22
	168	10.22	7.50	13.60	10.21	7.26	6.49	30.97	27.43
	336	12.71	9.01	16.85	16.21	10.82	8.13	30.80	38.05
Crab[2] waste	56	5.64	5.30	9.70	6.76	4.39	4.33	27.56	25.04
	168	9.22	5.70	14.20	8.40	6.12	5.47	33.76	27.95
	336	12.69	8.45	17.63	13.45	8.74	6.85	34.12	31.87
Control[3]	0	4.26		3.69		4.04		26.48	

[1] Average of three replications.

[2] Size fractions are shrimp waste, unground (1.27 cm) and crab waste, 1.27 cm.

[3] Control values are not included in the analysis of variance.

Table 14. ANOV I.[1] Effect of application method on forage yield.

Source of Variation	Degrees of Freedom	F Value
Method (of application)	1	45.20**
Crop (grass and association)	1	1912.71**
Crop x Method	1	0.21NS
Soil (Knappa and Nehalem)	1	682.05**
Soil x Method	1	10.17**
Soil x Crop	1	1016.67**
Fertilizer (shrimp and crab wastes)	1	3.42NS
Fertilizer x Method	1	6.12*
Fertilizer x Crop	1	1.66NS
Fertilizer x Soil	1	0.25NS
Rate (of application)	2	127.02**
Rate x Method	2	3.70*
Rate x Crop	2	9.31**
Rate x Soil	2	0.25NS
Rate x Fertilizer	2	0.72NS

Error mean square = 3.4613 with 94 d.f.

[1]Analysis of variance.

in the association yield between the two soils was a result of the greater growth of clover on the Nehalem soil compared to the Knappa soil (Table 36).

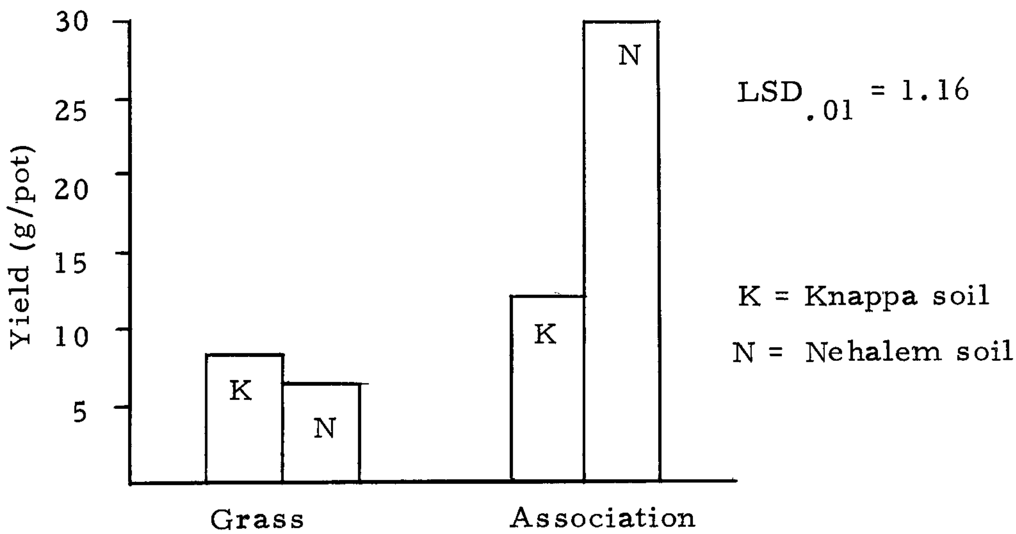

Figure 6. Yield of forage crops on Knappa and Nehalem soils.

Averaged over all other factors, the forage yield was significantly higher with mixed, waste applications than with surface waste applications (Tables 13 and 14). Mean forage yield values were 15.22 g/pot for mixed applications and 13.14 g/pot for surface applications. Mixed, waste applications resulted in higher forage yields than surface applications on both soils, at all N application rates, and with both waste materials (Table 13, Figures 7, 8, and 9).

Averaged over all other factors, forage yields were not significantly different with applications of either shrimp or crab wastes (Table 13 and 14), but surface applications of shrimp waste were more effective in increasing yields than surface applications of crab waste (Figure 7).

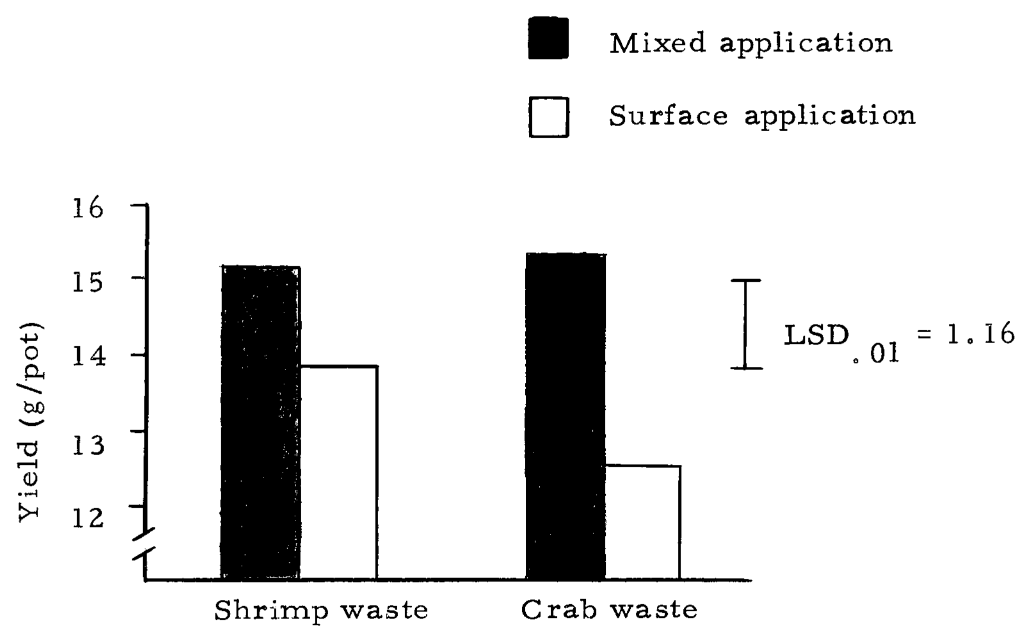

Figure 7. Forage yields with mixed and surface applications of shrimp and crab wastes.

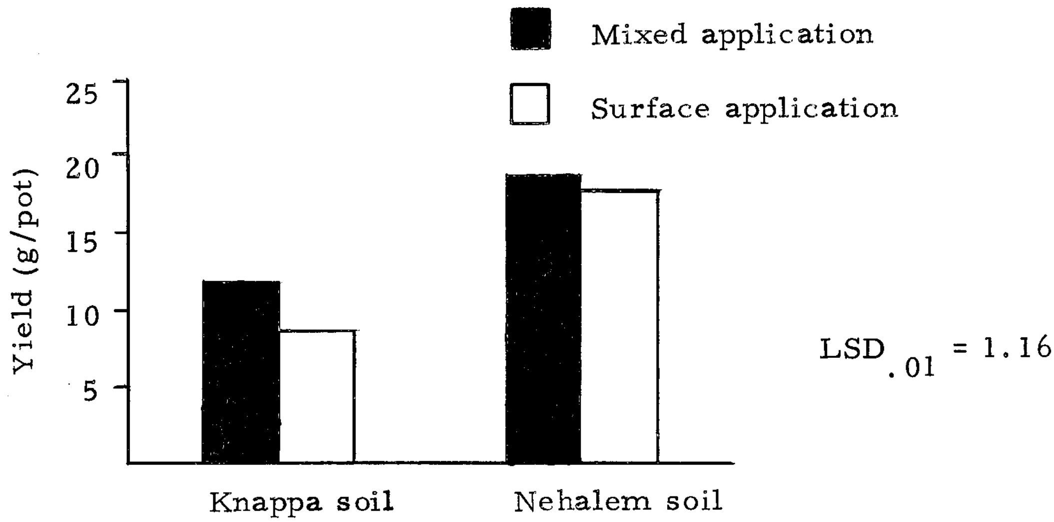

Figure 8. Forage yields with mixed and surface waste applications on Knappa and Nehalem soils.

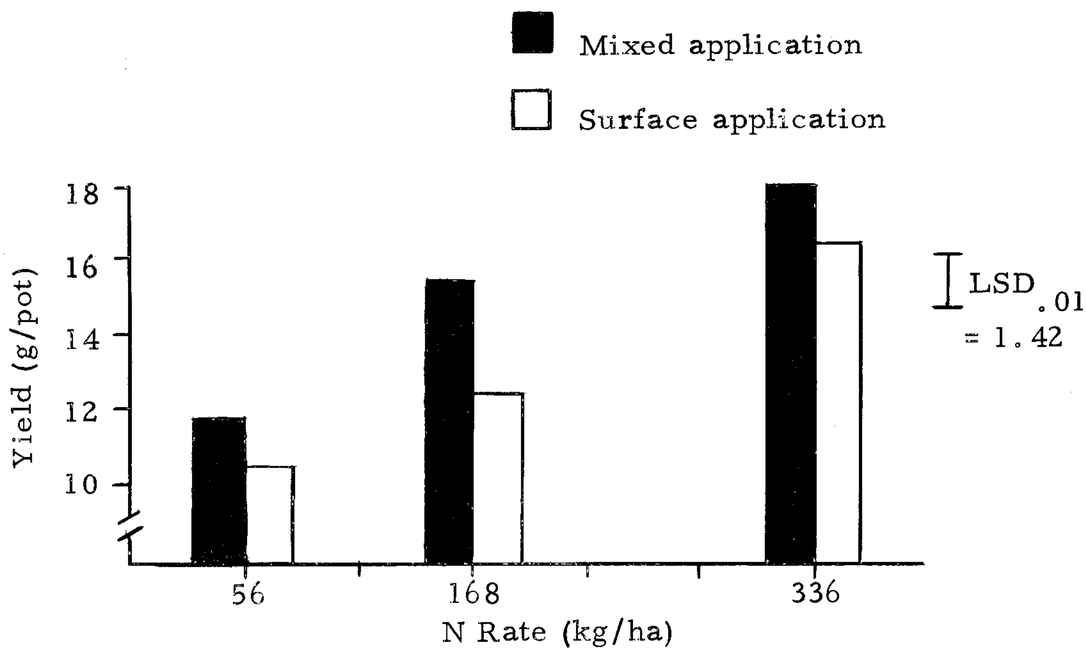

Figure 9. Forage yields with mixed and surface waste applications at three nitrogen application rates.

Averaged over all other factors, the N concentration of orchardgrass was not significantly different between mixed and surface waste applications (Tables 15 and 16). On the Knappa soil, the N concentration in orchardgrass was not significantly different between mixed and surface waste applications, but on the Nehalem soil, wastes mixed with the soil resulted in significantly higher N concentrations in the grass than surface applied wastes (Table 17).

Averaged over all other factors, the P concentration in the forage was significantly higher with mixed, waste applications than with surface applied wastes (Tables 18 and 19). Mean forage P concentrations were 0.26% for the mixed, waste applications and 0.24% for the surface, waste applications. The P concentration in orchardgrass was significantly higher with mixed, waste applications than with surface applications, but waste application method did not affect the P concentration in white clover (Table 20). Although white clover yields were generally higher with mixed applications than with surface applications (particularly on the Knappa soil, see Appendix Table 1b), white clover is apparently able to effectively utilize surface applications of shrimp and crab wastes as a source of P. Surface application of fertilizer materials is the only practical method on established permanent pastures and forage crops.

Table 15. Effect of application method on the nitrogen concentration in orchardgrass.

Fertilizer	Harvest	N rate	Knappa Soil		Nehalem Soil	
			Mixed	Surface	Mixed	Surface
	weeks after planting	Kg/ha	--------------------%N--------------------			
Shrimp waste[1]	14	56	3.54	3.26	1.77	1.95
		168	3.43	3.59	2.38	1.90
		336	3.43	3.69	2.63	2.13
	28	56	1.02	1.23	1.62	1.42
		168	1.38	1.09	1.81	1.77
		336	1.17	1.25	1.74	1.40
Crab waste[1]	14	56	3.60	3.65	1.63	1.81
		168	3.35	3.45	2.75	2.09
		336	3.60	3.58	3.24	2.83
	28	56	1.16	1.24	1.83	1.45
		168	1.33	1.33	1.74	1.53
		336	1.54	1.41	1.67	1.42
Control	14	0	3.82		1.78	
	28	0	1.29		1.55	

[1] Size fractions are shrimp waste, unground (1.27 cm) and crab waste, 1.27 cm.

Table 16. ANOV II. Effect of application method on the nitrogen concentration in orchardgrass.

Source of Variation	Degrees of Freedom	F Value
Method (of application)	1	1.68 NS
Method x Soil	1	11.81 **
Method x Fertilizer (wastes)	1	1.40 NS
Method x Harvest (period)	1	3.40 NS
Method x Rate (of application)	2	3.33 NS
Error mean square = 0.1080 with 90 d.f.[1]		

[1] 94 d.f. - 4 estimated values (Steel and Torrie 1960).

Table 17. Nitrogen concentration in orchardgrass with mixed and surface waste applications on Knappa and Nehalem soils.

Application Method	Knappa Soil	Nehalem Soil
	%N	%N
Mixed	2.28	2.07
Surface	2.39	1.81

$LSD_{.01} = 0.204$, $LSD_{.05} = 0.154$, $S_{\bar{x}} = .055$

Table 18. Effect of application method on the phosphorus concentration in orchardgrass and white clover.

Fertilizer	Harvest	Knappa Soil				Nehalem Soil			
		Grass		Clover		Grass		Clover	
		Mixed	Surface	Mixed	Surface	Mixed	Surface	Mixed	Surface
	weeks after planting	%P							
Shrimp waste[1]	7	.25	.19	.27	.26	.28	.24	.33	.30
	14	.19	.15	.26	.26	.21	.18	.32	.34
Crab waste[1]	7	.22	.24	.26	.24	.28	.24	.31	.28
	14	.21	.14	.29	.28	.20	.16	.28	.32
Control	7	.17		.22		.25		.28	
	14	.13		.24		.18		.24	

[1] Size fractions are shrimp waste, unground (1.27 cm) and crab waste, 1.27 cm, applied at the 168 kg/ha N rate.

Table 19. ANOV III. Effect of application method on the phosphorus concentration in orchardgrass and white clover.

Source of Variation	Degrees of Freedom	F Value
Method (of application)	1	14.67 **
Method x Crop	1	7.17 **
Method x Soil	1	0.14 NS
Method x Fertilizer (wastes)	1	0.19 NS
Method x Harvest (period)	1	0.84 NS
Error mean square = 0.0009 with 62 d.f.		

Table 20. Phosphorus concentration in orchardgrass and white clover with mixed and surface waste applications.

Application Method	Orchardgrass	White Clover
	----------%P----------	
Mixed	0.23	0.29
Surface	0.19	0.28
$LSD_{.01}$ = 0.023, $LSD_{.05}$ = 0.017, $s_{\bar{x}}$ = 0.006		

In the greenhouse, shrimp and crab wastes mixed with the soil were generally superior to surface applied wastes in terms of forage yields and the N and P concentrations in the forage plants. It is likely that the differences between mixed and surface waste applications would be much less under field conditions. In the greenhouse, the pots were carefully watered and disturbance was at a minimum. Even after 10 months, surface applied waste material remained on the soil surface and, except for loosing color, was still recognizable. Mixed material was found only as chalky areas in the soil. Some of the shell material in closest contact with the soil became thoroughly permeated with roots and would crumble into a fine dust with slight pressure. Field conditions are quite different. Several observations of light to heavy surface applications of shrimp processing waste (estimated range of 3 to 20 T/A) on permanent grass-clover pastures were made. After about three to four months, much of the waste material was no longer visible on the soil surface. After about six to eight months, no waste material was visible and digging in the top few inches of soil revealed only small pieces of remaining shell.

In the greenhouse, surface applications of shrimp waste were more effective in increasing yields than surface applications of crab, but no significant yield differences occurred between the waste materials when mixed with the soil. Surface applied crab processing waste may be more resistant to decomposition and incorporation into the soil under field conditions than shrimp waste because the crab shell material is much larger, thicker, and more substantial than shrimp shell.

Field conditions and activities that may contribute to the incorporation of surface applied shrimp and crab processing wastes with the soil would include the action of rain, irrigation water, grazing animals, field machinery, and soil animals.

Effect of Grinding

The effect of grinding shrimp and crab wastes on forage yield was measured using the Knappa soil (Tables 21, 22, 23, and 24).

Averaged over all other factors, no significant difference in forage yield occurred among the three size fractions of crab waste when the waste was mixed with the soil (Table 21, Figure 10). When surface applied, however, each successively smaller size fraction of crab waste significantly increased the forage yield (Figure 10). The smallest size fraction of crab waste surface applied resulted in significantly lower forage yields than the largest size fraction mixed with the soil (Figure 10).

Crab waste from the processing plant consists of pieces significantly larger than the largest size fraction (2.54 cm) used in this experiment. Crab shells, including backs and leg shells, are

Table 21. Effect of grinding crab waste on forage yield.

Size Fraction	N rate	Grass		Association	
		Mixed	Surface	Mixed	Surface
----cm----	kg/ha	-----------------------g/pot-----------------------			
2.54	56	6.51	4.74	9.75	5.11
	168	8.55	4.94	12.60	6.65
	336	10.19	6.02	17.78	8.75
1.27	56	5.64	5.30	9.70	6.76
	168	9.22	5.70	14.20	8.40
	336	12.69	8.45	17.63	13.45
0.32	56	7.82	5.75	8.63	7.38
	168	8.03	6.62	14.22	11.73
	336	12.24	8.95	18.48	15.66
Control	0	4.26		3.69	

Table 22. ANOV IV. Effect of grinding crab waste on forage yield.

Source of Variation	Degrees of Freedom	F Value
Grinding	2	24.18 **
Grinding x Method (of application)	2	10.28 **
Grinding x Crop	2	2.01 NS
Grinding x Rate (of application)	4	3.11 *
Error mean square = 1.5251 with 70 d.f.		

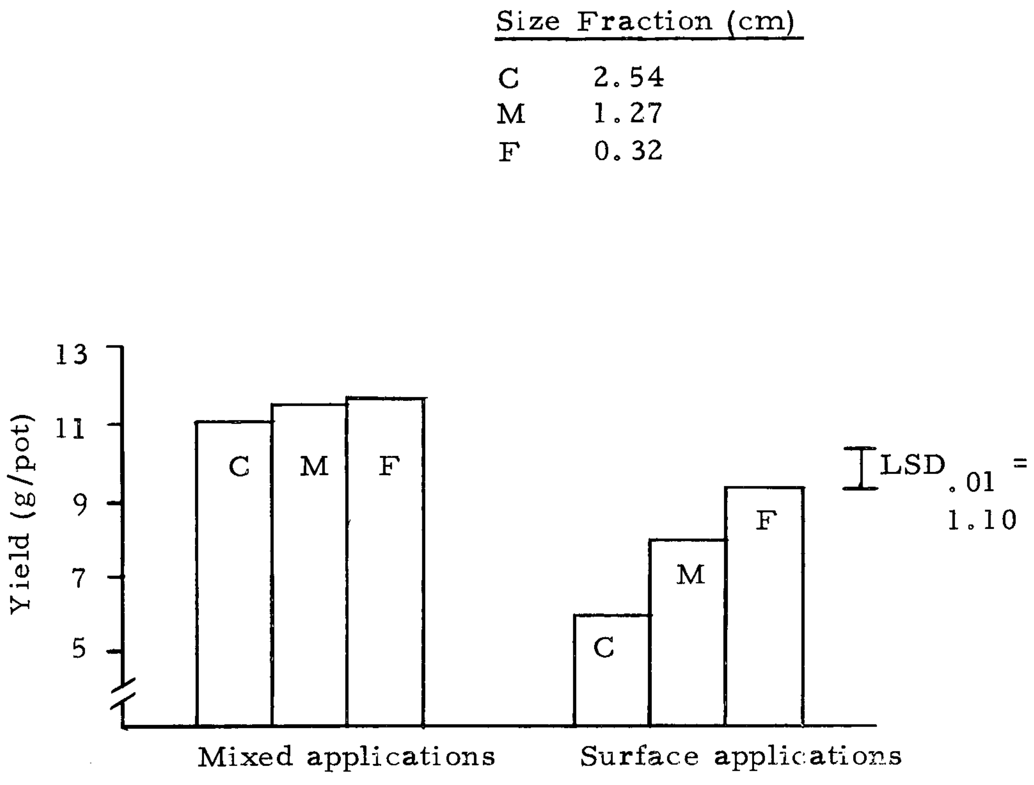

Figure 10. Effect of grinding crab waste on forage yield with mixed and surface waste applications.

commonly in the range of 4 to 20 cm. The results of this experiment indicate that the large size may not be a disadvantage if the crab shell material is mixed with the soil, but some method of breaking the shell would be beneficial if the material is surface applied. Methods of breaking the shell material could include the action of grazing animals, light disking, or cultivation associated with pasture renovation.

Unground shrimp waste (1.27 cm) resulted in a significantly higher forage yield than shrimp waste ground to 0.32 cm, when averaged over all other factors (Tables 23 and 24). When mixed with the soil, unground shrimp waste gave significantly higher forage yields than ground shrimp waste, but no difference occurred between size fractions when the waste was surface applied (Table 25).

Comparisons of Shrimp Waste, Crab Waste, and Inorganic Fertilizer-Lime Treatments

To determine their fertilizer value, shrimp and crab waste applications of the 1.27 cm size fraction (unground in the case of shrimp), mixed with the soil, were compared with inorganic nutrient applications.

Averaged over all other factors, no significant difference in forage yield occurred among the three fertilizer materials

Table 23. Effect of grinding shrimp waste on forage yield.

Size Fraction	N rate	Grass		Association	
		Mixed	Surface	Mixed	Surface
----cm----	kg/ha	----------g/pot----------			
1.27	56	7.48	5.56	10.04	6.53
(unground)	168	10.22	7.50	13.60	10.21
	336	12.71	9.01	16.85	16.21
0.32	56	6.33	4.77	6.62	9.80
	168	8.81	7.03	11.36	11.88
	336	11.11	8.69	15.79	13.91
Control	0	4.26		3.69	

Table 24. ANOV V. Effect of grinding shrimp waste on forage yield.

Source of Variation	Degrees of Freedom	F Value
Grinding	1	10.38 **
Grinding x Method (of application)	1	15.31 **
Grinding x Crop	1	0.30 NS
Grinding x Rate (of application)	2	0.99 NS
Error mean square = 1.1594 with 46 d.f.		

Table 25. Forage yields for ground and unground shrimp waste with mixed and surface applications.

Size Fraction	Mixed	Surface
-----cm-----	------------g/pot------------	
1.27 (unground)	11.81	9.17
0.32	10.00	9.35
$LSD_{.01} = 0.966$, $LSD_{.05} = 0.723$, $S_{\bar{x}} = 0.254$		

(Table 26 and 27). At the 56 kg/ha N rate of application, shrimp and crab wastes gave similar forage yields, but applications of inorganic fertilizer--lime resulted in significantly higher forage yields than the wastes (Table 26, Figure 11). At the 56 kg/ha N rate of application, P, S, and lime additions were substantially higher with the inorganic fertilizer-lime treatments than with the processing waste treatments (Tables 6 and 7). At the 168 and 336 kg/ha N application rates, the forage yield was not significantly different (at the 1% level) among the three fertilizer materials (Figure 11).

Nitrogen uptake by orchardgrass was calculated for the 168 kg/ha N rate of application for each of the four harvest periods (Table 28). This N rate was appropriate because P additions were comparable from all fertilizer materials. For each replicate, at each harvest, N uptake (mg/pot) was calculated by,

$$\% \text{ N} \times \text{yield (g/pot)} \times 10.$$

Averaged over all other factors, the N uptake by orchardgrass was not significantly different from the three fertilizer materials (Tables 28 and 29). The lack of a significant interaction between the fertilizer materials and the harvest periods (Table 29) indicates that the N uptake for each harvest period was similar from the shrimp waste, the crab waste, and the inorganic N sources (Figure 12). Evidently, shrimp waste and crab waste are not slow release

Table 26. Effect of shrimp waste, crab waste, and inorganic fertilizer-lime on forage yield.

Fertilizer Material	N rate	Knappa Soil		Nehalem Soil	
		Grass	Association	Grass	Association
	kg/ha	g/pot			
Shrimp waste	56	7.48	10.04	5.12	25.62
	168	10.22	13.60	7.26	30.97
	336	12.71	16.51	10.82	30.80
Crab waste	56	5.64	9.70	4.39	27.56
	168	9.22	14.20	6.12	33.76
	336	12.69	17.63	8.74	34.12
Inorganic-lime	56	8.23	14.58	6.08	28.54
	168	10.23	15.22	8.04	29.66
	336	12.05	16.16	10.96	26.55
Control	0	4.26	3.69	4.04	26.48

Table 27. ANOV VI. Effect of fertilizer material on forage yield.

Source of Variation	Degrees of Freedom	F Value
Fertilizer (inorganic and wastes)	2	0.49 NS
Fertilizer x Crop	2	6.72 **
Fertilizer x Soil	2	3.14 *
Fertilizer x Rate (of application)	4	5.63 **

Error mean square = 2.9761 with 70 d. f.

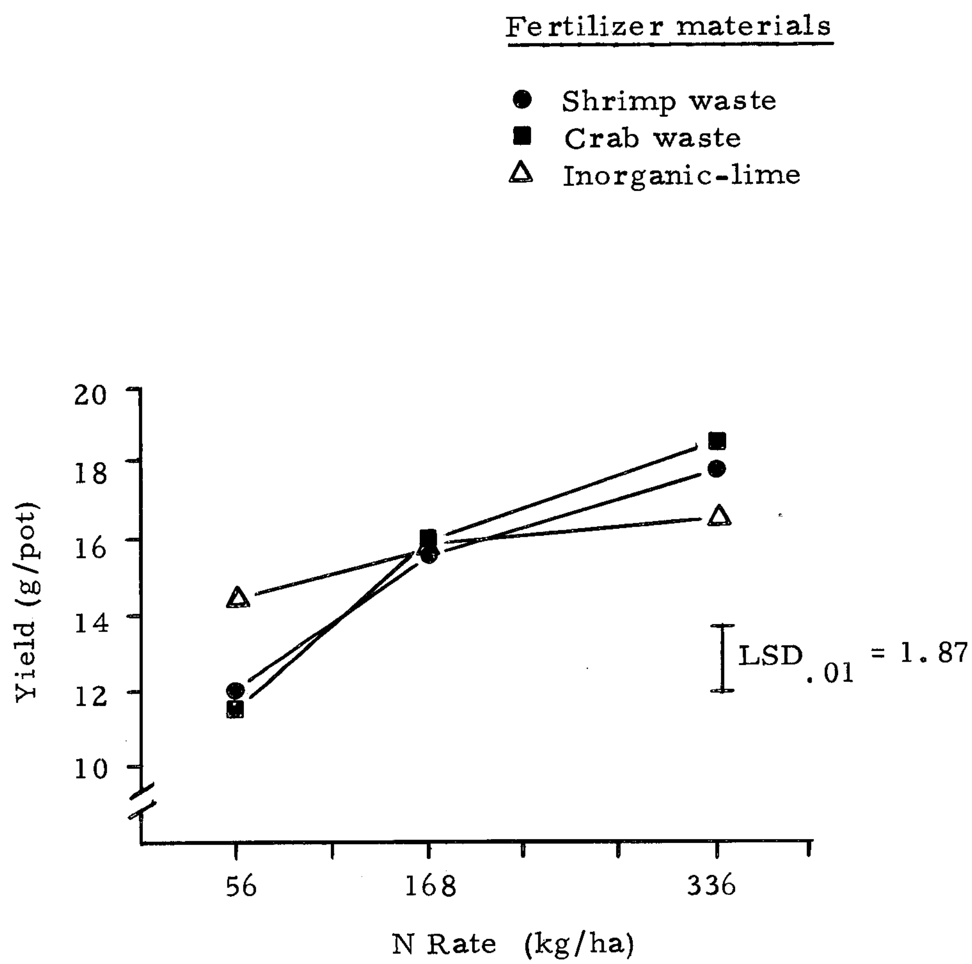

Figure 11. Effect of nitrogen application rate on forage yield with shrimp waste, crab waste, and inorganic fertilizer - lime applications.

Table 28. Effect of fertilizer material on the nitrogen uptake by orchardgrass for each harvest period at the 168 kg/ha nitrogen application rate.

	Knappa Soil				Nehalem Soil			
	Harvest (weeks after planting)							
Fertilizer Material	7	14	21	28	7	14	21	28
	mg/pot							
Shrimp waste	27.37	101.62	99.07	30.42	58.62	93.30	18.41	8.45
Crab waste	27.04	116.79	68.35	9.95	43.44	105.55	22.85	7.01
Inorganic-lime	35.36	126.18	83.39	20.84	60.92	114.26	22.37	9.85
Control	7.37	30.02	44.27	25.56	35.09	28.34	11.03	10.16

Table 29. ANOV VII. Effect of fertilizer material on nitrogen uptake by orchardgrass.

Source of Variation	Degrees of Freedom	F Value
Fertilizer (inorganic and wastes)	2	2.32 NS
Fertilizer x Soil	2	0.60 NS
Fertilizer x Harvest (period)	6	1.58 NS
Error mean square = 210.5913 with 44 d.f.[1]		

[1] 46 d.f. - 2 estimated values.

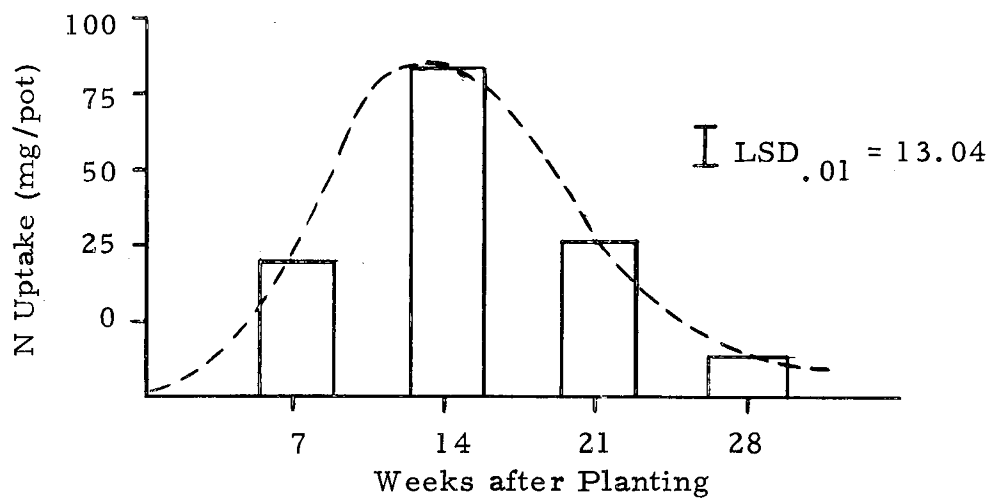

Figure 12. Nitrogen uptake for each harvest period averaged over all fertilizer materials.

N sources as compared to ammonium nitrate (and monoammonium phosphate).

Averaged over all other factors, the P concentrations in orchardgrass and white clover were not significantly different among applications of the three fertilizer materials at the 168 kg/ha N application rate (Tables 30, 31, 32 and 33). However, on the Knappa soil, applications of crab waste resulted in significantly higher P concentrations in white clover than applications of shrimp waste or the inorganic fertilizers (Table 34). The intimate mixture

Table 30. Effect of fertilizer material on the phosphorus concentration in orchardgrass at the 168 kg/ha nitrogen application rate.

	Knappa Soil		Nehalem Soil	
	Harvest (weeks after planting)			
Fertilizer Material	7	14	7	14
	% P			
Shrimp waste	0.25	0.19	0.28	0.21
Crab waste	0.22	0.21	0.28	0.20
Inorganic-lime	0.24	0.16	0.27	0.19
Control	0.17	0.13	0.25	0.18

of $CaCO_3$ and P in the wastes might have enhanced the availability of the P in the acid coastal soils. Some of the P contained in the wastes might have been taken up by the forage plants without contact of the P with the soil.

Table 31. ANOV VIII. Effect of fertilizer material on the phosphorus concentration in orchardgrass.

Source of Variation	Degrees of Freedom	F Value
Fertilizer (inorganic and wastes)	2	2.54 NS
Fertilizer x Soil	2	0.11 NS
Fertilizer x Harvest (period)	2	1.34 NS

Error mean square = 0.0004 with 22 d.f.

Table 32. Effect of fertilizer material on the phosphorus concentration in white clover at the 168 kg/ha nitrogen application rate.

	Knappa Soil			Nehalem Soil		
	Harvest (weeks after planting)					
Fertilizer Material	14	28	42	14	28	42
	% P					
Shrimp waste	0.26	0.15	0.10	0.32	0.20	0.14
Crab waste	0.29	0.18	0.16	0.28	0.20	0.11
Inorganic-lime	0.31	0.13	0.11	0.31	0.19	0.10
Control	0.24	0.14	0.08	0.28	0.17	0.16

Table 33. ANOV IX. Effect of fertilizer material on the phosphorus concentration in white clover.

Source of Variation	Degrees of Freedom	F Value
Fertilizer (inorganic and wastes)	2	0.95 NS
Fertilizer x Soil	2	7.01 **
Fertilizer x Harvest (period)	4	2.16 NS

Error mean square = 0.0007 with 34 d.f.

Table 34. Phosphorus concentrations in white clover for the fertilizer materials on Knappa and Nehalem soils.

Fertilizer Material	Knappa Soil	Nehalem Soil
	- - - - - - - - % P - - - - - - - - -	
Shrimp waste	0.17	0.22
Crab waste	0.21	0.20
Inorganic-lime	0.18	0.20

$LSD_{.01} = 0.031$, $LSD_{.05} = 0.026$, $s_{\overline{x}} = 0.009$

Enhancement of White Clover Growth on an Acid Soil From Applications of Shrimp and Crab Wastes

White clover is sensitive to acid soil conditions. Optimum yields of white clover on acid soils are commonly only obtained by liming to pH 5.5 to 5.8 (Gammon and Blue, 1968; Sanford et al. 1968).

Applications of shrimp and crab wastes did not increase the pH of the Knappa soil above the initial value of 5.0, but applications of the inorganic fertilizer-lime increased the soil pH to 5.6 (Table 35). Only slight differences occurred among the pH values of the Nehalem soil with applications of the fertilizer materials (Table 35).

Table 35. Range of soil pH values for all application rates of each fertilizer material measured after the last grass-clover association harvest.

Fertilizer Material	Knappa Soil	Nehalem Soil
	------- pH Range	------
Control	4.9	5.3
Shrimp waste	4.9-5.0	5.4-5.5
Crab waste	4.9-5.0	5.3-5.4
Inorganic-lime	5.6	5.5-5.6

On the Nehalem soil, only two fertilizer treatments resulted in white clover yields significantly different from the control: one higher and one lower (Table 36). On the Knappa soil, all fertilizer treatments resulted in significantly higher clover yields than the control, but there were no significant differences in the white clover yield among fertilizer materials (Table 36, Figure 13).

The growth of white clover on the acid, untreated Knappa soil was probably restricted due to high Al concentrations in the soil, poor or ineffective root nodulation, and low availability of P, Ca, Mo, or other essential elements. The leaves on the clover plants of the control became almost entirely yellow or yellow-red, a common N deficiency symptom. White clover rhizobia can survive and multiply at pH 4.8, but nodulation is limited (Loos and Louw, 1965).

White clover yields on the Knappa soil generally increased over time with applications of the shrimp and crab wastes (and the inorganic fertilizer-lime), assumably due to symbiotic N fixation and increased availability of essential elements (Figure 13). The white clover did not directly respond to the N supplied, for the pattern of grass growth suggested that most of the readily available N had been taken up by the end of the third harvest period (Figures 12 and 13). The general increase in clover yields with time indicated that clover growth was not restricted by competition with

Table 36. Effect of fertilizer material on the yield of white clover.

N rate	Fertilizer Material	Knappa Soil	Nehalem Soil
(kg/ha)		------------g/pot----------	
0	Control	1.38 a[1]	23.46 a
56	Shrimp waste	5.21 b	22.54 a
	Crab waste	5.21 b	24.34 a
	Inorganic-lime	8.79 b	24.23 a
168	Shrimp waste	5.65 b	25.96 ab
	Crab waste	8.24 b	29.39 b
	Inorganic-lime	7.78 b	23.83 a
336	Shrimp waste	6.47 b	23.96 a
	Crab waste	7.74 b	27.27 ab
	Inorganic-lime	6.91 b	16.48 c
		$s_{\bar{x}} = 1.081$	$s_{\bar{x}} = 1.536$

[1] Means within soils that do not have a letter in common differ significantly at the 5% level of probability by Duncan's new multiple range test.

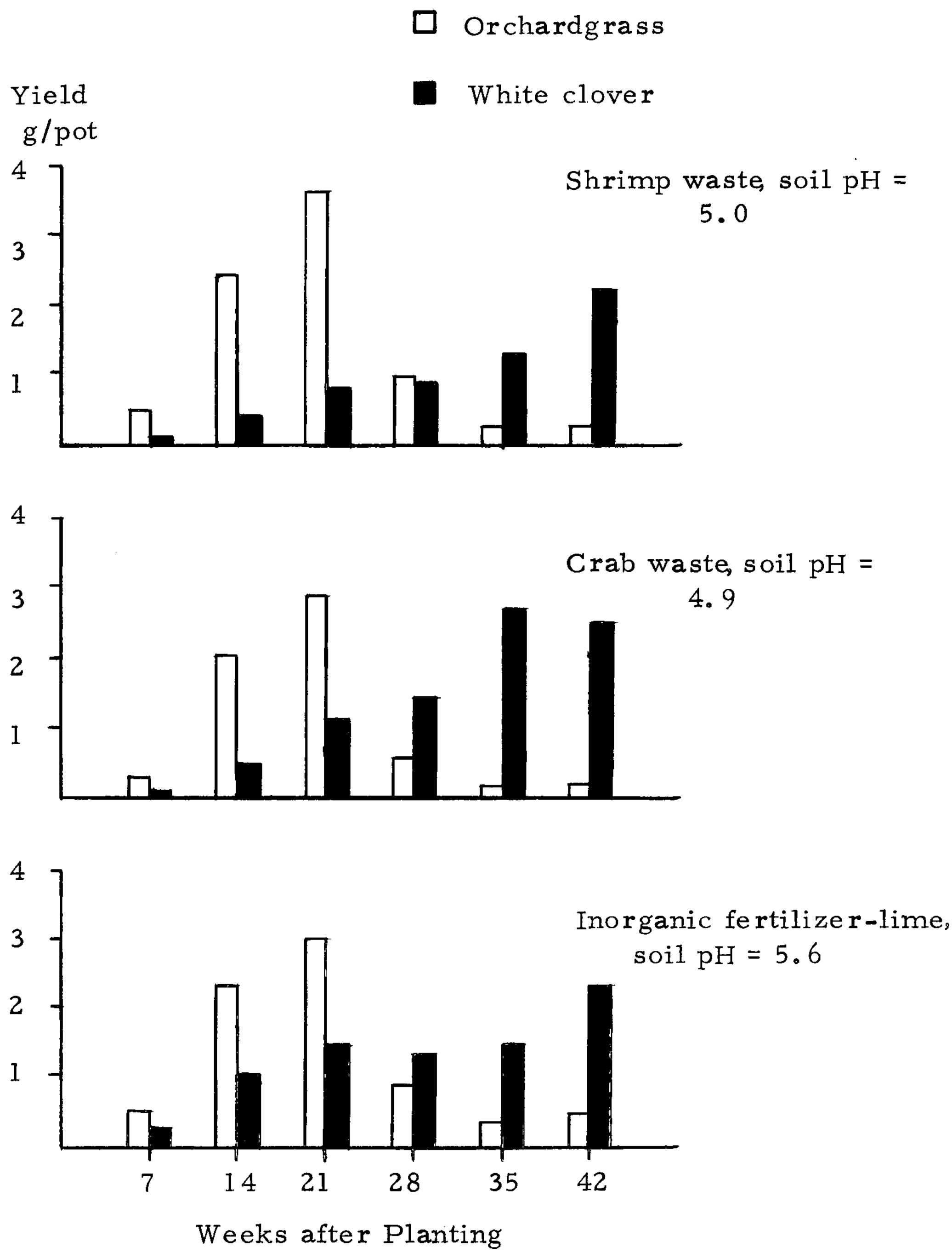

Figure 13. Orchardgrass and white clover yields on the Knappa soil at each harvest period for each fertilizer material at the 168 kg/ha rate of nitrogen application.

the grass for light (Figure 13).

The roots of both forage species flourished in the area of shrimp and crab waste material. The roots commonly grew out of the soil and permeated surface applied shrimp and crab shell material in close contact with the soil surface. On the acid Knappa soil, nodulation, symbiotic N fixation by white clover, and the availability of essential elements were assumably enhanced by microenvironmental conditions in the immediate area of the shrimp and crab wastes. The detrimental effects of acid soil on nodulation can be overcome to some extent by increasing the Ca concentration (Loneragan and Dowling 1958). The dry wastes contained 15% to 20% Ca and had a $CaCO_3$ equivalence of 30% to 40%. A neutralizing effect in the immediate area of the wastes might have increased the availability of Ca and P from the wastes, increased the availability of soil P and Mo, and decreased the soluble soil Al. Some of the P contained in the wastes might have been taken up by clover roots without contact of the P with the soil. Sulfur and other plant nutrient elements are contained in shrimp and crab wastes and might become available to plant roots in the soil.

Applications of shrimp and crab processing wastes to an acid coastal soil did not measurably increase the soil pH, but substantially enhanced the growth of white clover. Shrimp and crab waste applications supply significant rates of N. Application of N on grass-clover mixtures requires careful management to maintain the clover component.

The following information is not directly related to the greenhouse study, but sheds some light on the liming value of shrimp and crab wastes. In 1965, high rates of shrimp and crab processing wastes (approximately 50 to 150 T/A in one season) were applied on a coastal hill pasture in Oregon (Glenn Wagner Ranch, Port Orford). The soil pH increased from the original value of 5.0 to a value of 6.1 approximately four to five months after application and to a value of 6.9 approximately nine to ten months after application (Appendix Table 6). The level of soil NO_3-N was excessively high (338 ppm in the top 15 cm) when sampled four to five months after application (see Appendix Table 6 for other soil test values). Applications of high rates of shrimp and crab processing wastes are not recommended because of possible NO_3 pollution of groundwater and excess NO_3 uptake by forage species. Moderate annual applications (1.5 to 10 T/A) can overcome some of the harmful effects of soil acidity and may gradually increase the soil pH over a period of years.

Effect of Application Rate of Shrimp and Crab Wastes on Yield, and Plant and Soil Composition

Linear regression and correlation techniques were applied to determine functional relationships between the application of the waste materials and subsequent plant and soil characteristics. It is not assumed that a linear description is the best fit for the data in every case.

For each plant and soil characteristic of interest, a regression equation and a simple correlation coefficient (r) were determined for each crop on each soil with each fertilizer material. The fertilizer treatments examined were mixed applications of shrimp waste (unground) and crab waste (1.27 cm). Twelve values for each treatment were applied to the regression and correlation determinations, and were obtained from the three replicates at each of the four application rates (0, 56, 168, 336 kg N/ha). Soil composition results are for orchardgrass treatments sampled 28 weeks after waste application.

With increasing application rate of shrimp and crab wastes, the yield of orchardgrass and the orchardgrass-white clover association increased significantly on both soils (Table 37), the N concentration in orchardgrass increased significantly on the Nehalem soil, but not on the Knappa soil (Table 38), the P concentration in orchardgrass and white clover increased significantly on both soils (Tables 39 and 40), the extractable soil Ca increased significantly on both soils (Table 44), the extractable soil P increased significantly with shrimp applications on both soils and with crab applications on the Nehalem soil (Table 42), the extractable soil Mg increased slightly, but not significantly in each case (Table 45), the extractable soil K decreased significantly on both soils (Table 43), and no significant effect on soil pH was measured (Table 41).

Table 37. Effect of application rate of shrimp and crab wastes on forage yield.

Crop	Soil	Fertilizer (Wastes)	Linear Regression	r
Orchardgrass	Knappa	Shrimp	5.37 + .026 x	.95 **
		Crab	4.39 + 0.29 x	.99 **
	Nehalem	Shrimp	3.98 + .022 x	.99 **
		Crab	3.80 + .016 x	.99 **
Association	Knappa	Shrimp	6.11 + .040 x	.91 **
		Crab	5.95 + .043 x	.91 **
	Nehalem	Shrimp	26.25 + .018 x	.63 *
		Crab	27.06 + .027 x	.68 *

Table 38. Effect of application rate of shrimp and crab wastes on nitrogen concentration in orchardgrass at harvest period two.

Soil	Fertilizer (Wastes)	Linear Regression	r
Knappa	Shrimp	3.69 - .001 x	-.48 NS
	Crab	3.67 - .001 x	-.32 NS
Nehalem	Shrimp	1.75 + .003 x	.77 **
	Crab	1.66 + .005 x	.87 **

Table 39. Effect of application rate of shrimp and crab wastes on phosphorus concentration in orchardgrass at harvest period two.

Soil	Fertilizer (Wastes)	Linear Regression	r
Knappa	Shrimp	0.14 + .0002 x	.82 **
	Crab	0.14 + .0002 x	.81 **
Nehalem	Shrimp	0.18 + .0001 x	.63 *
	Crab	0.17 + .0001 x	.62 *

Table 40. Effect of application rate of shrimp and crab wastes on phosphorus concentration in white clover at harvest period four.

Soil	Fertilizer (Wastes)	Linear Regression	r
Knappa	Shrimp	0.12 + .0002 x	.75 **
	Crab	0.13 + .0002 x	.76 **
Nehalem	Shrimp	0.17 + .0001 x	.67 *
	Crab	0.18 + .0001 x	.62 *

Table 41. Effect of application rate of shrimp and crab wastes on soil pH.

Soil	Fertilizer (Wastes)	Linear Regression	r
Knappa	Shrimp	5.00 - .0006 x	-.65 *
	Crab	5.00 + .0004 x	.68 *
Nehalem	Shrimp	5.42 + .0004 x	.39 NS
	Crab	5.42 + .0004 x	.41 NS

Table 42. Effect of application rate of shrimp and crab wastes on extractable soil phosphorus.

Soil	Fertilizer (Wastes)	Linear Regression	r
Knappa	Shrimp	10.65 + .021 x	.73 **
	Crab	10.11 - .002 x	-.24 NS
Nehalem	Shrimp	16.97 + .025 x	.87 **
	Crab	17.63 + .012 x	.74 **

Table 43. Effect of application rate of shrimp and crab wastes on extractable soil potassium.

Soil	Fertilizer (Wastes)	Linear Regression	r
Knappa	Shrimp	124.24 - .195 x	-.83 **
	Crab	138.97 - .225 x	-.97 **
Nehalem	Shrimp	168.84 - .265 x	-.95 **
	Crab	168.11 - .102 x	-.69 *

Table 44. Effect of application rate of shrimp and crab wastes on extractable soil calcium.

Soil	Fertilizer (Wastes)	Linear Regression	r
Knappa	Shrimp	1.55 + .005 x	.97 **
	Crab	1.44 + .007 x	.99 **
Nehalem	Shrimp	7.72 + .006 x	.84 **
	Crab	7.92 + .007 x	.85 **

Table 45. Effect of application rate of shrimp and crab wastes on extractable soil magnesium.

Soil	Fertilizer (Wastes)	Linear Regression	r
Knappa	Shrimp	0.80 + .0002 x	.68 *
	Crab	0.78 + .0001 x	.27 NS
Nehalem	Shrimp	3.16 + .0010 x	.49 NS
	Crab	3.25 + .0010 x	.67 *

Summary and Conclusions

In the greenhouse, applications of shrimp and crab processing wastes increased the yields and the N and P concentrations of orchardgrass and white clover. Soil incorporated waste applications were more effective than surface applied wastes. Under field conditions, the difference between soil incorporated and surface waste applications would be reduced because rain, irrigation water, grazing animals, field machinery, and soil animals bring the waste material into close contact with the soil.

Grinding did not increase the effectiveness of shrimp waste. When incorporated with the soil, grinding did not increase the effectiveness of crab waste, however, each successively smaller size fraction of crab waste increased forage yields when surface applied. Because the pieces of shell in crab waste are relatively large, breaking the shell material and increasing the shell to soil contact would be beneficial if the crab waste material is surface applied and not incorporated into the soil.

When applied at equivalent rates of N and comparable rates of P, forage yields, the N uptake by orchardgrass, and the P concentrations in orchardgrass and white clover were not significantly different among applications of shrimp waste, crab waste, and inorganic nutrients with ground limestone. The waste materials were not slow release sources of N compared to ammonium nitrate in combination with monoammonium phosphate.

The growth of white clover on an acid coastal soil (pH 4.9 - 5.0) in the greenhouse was substantially increased with applications of shrimp and crab wastes and with applications of inorganic nutrients with ground limestone. Applications of the inorganic nutrients with lime increased the soil pH (to 5.6), but applications of the wastes did not. White clover growth and symbiotic N fixation were assumably enhanced by conditions, in the immediate area of the wastes, of increased availability of Ca, P, Mo, and S, and decreased solubility of Al. Phosphorus might have been taken up directly from the waste material without direct contact of the P with the soil.

With applications of shrimp and crab wastes, the extractable soil Ca and P increased, and the extractable soil K decreased. The decrease in soil K was assumably due to crop uptake. No significant effect on soil pH was measured.

Experiment II

Introduction

Before farmers substitute shrimp and crab processing wastes for conventional fertilizers on a large scale, the comparative value and recovery of the nutrients contained in the wastes need to be evaluated.

To determine the comparative value of shrimp processing wastes as a source of N and P in relation to conventional inorganic sources, the fertilizer materials were applied to supply equivalent N and P rates, then orchardgrass yields, N uptake, and P uptake by the grass were compared.

Materials and Methods

Treatments

Two rates each of N and P in all combinations, supplied by shrimp processing wastes and inorganic sources, were applied to a limed coastal soil in a greenhouse study. To complete the factorial design, additional inorganic N or P was applied to supplement the shrimp waste (Table 46). Nutrient applications are on a weight basis assuming one hectare of soil 15 cm deep weighs 2,242,000 kg.

Table 46. Shrimp waste and inorganic nitrogen and phosphorus application rates.

Nutrient levels	Equivalent Application Rates N	P	Fertilizer Treatments Shrimp[1]	Inorganic
	--- kg/ha ----		g/pot	
N_1P_1	165.4	61.0	2.05	AN and MCP[2]
N_1P_2	165.4	122.0	2.05 + MCP	AN and MCP
N_2P_1	330.8	61.0	2.05 + AN	AN and MCP
N_2P_2	330.8	122.0	4.10	AN and MCP

[1]Oven dry (60 °C).

[2]Ammonium nitrate and monocalcium phosphate respectively.

Fertilizer Materials

Shrimp processing waste from the New England Fish Company, Newport, Oregon was air-dried in the greenhouse with no further processing (Table 9).

Inorganic N and P were supplied by reagent grade ammonium nitrate and monocalcium phosphate monohydrate.

Soil

Additional Knappa silt loam was obtained from the same site outlined for greenhouse experiment I (Table 47).

Table 47. Soil chemical analysis of Knappa silt loam.[1]

pH	SMP	P	K	B	Ca	Mg	Total-N	OM
		---- ppm ----			meq/100 g		--- % ---	
5.0	5.2	7	198	0.21	1.0	0.54	0.28	12.0

[1]Soil analysis by methods outlined in Table 11.

Procedure

Air-dry soil (1.62 kg) was weighed into plastic pots with a bottom drainage hole. An application of finely ground limestone equivalent to 11, 995 kg lime/ha (5.3 T/A) was added to each pot to raise the soil pH to 5.8 (Table 47) (Department of Soil Science 1972). Lime, shrimp waste, and inorganic P were thoroughly mixed with the soil from appropriate pots in a twin-shell dry blender. The pots were seeded with orchardgrass (Dactylis glomerata L.) 'Potomac', and the soil was brought to near field capacity with distilled water on June 26, 1976. The inorganic N was added in solution to the appropriate pots. After germination, the plants were thinned to 12 per pot. The plant material was harvested four times at approximately equal intervals with the last cutting on December 3, 1976 for a total growing period of 160 days. The plants were clipped to a height of 1.5 cm except for the last harvest when all plant material above the soil surface was removed. The harvested plant material was oven dried at 65°C for two to three days and weighed to determine yields. Samples were ground in a wiley mill and assayed for N and P concentrations (Table 12). Greenhouse conditions were the same as outlined for greenhouse experiment I.

Statistical Analysis

The uptake of N and P was calculated by multiplying grass yield by the nutrient concentration for each replicate at each harvest. The cumulative uptake for each replicate was obtained by summing the uptake values for all harvests.

The treatments were arranged in a 2 x 2 x 2 complete factorial with four replications employing a randomized complete block design. An analysis of variance was performed for cumulative yield, N uptake, and P uptake, and F values were determined.

All data are listed in Appendix Tables 7, 8 and 9.

EXPERIMENT 2

Results and Discussion

Applications of shrimp waste resulted in significantly higher orchardgrass yields than applications of inorganic nutrients (Tables 48 and 49).

Phosphorus uptake by orchardgrass was significantly higher from the shrimp waste than from the inorganic nutrients (Tables 48 and 49). The P uptake from the water soluble monocalcium phosphate may have been reduced because of the small particle size of the reagent grade material, and substantial contact with the soil (Bouldin et al. 1960).

The N uptake by orchardgrass was not significantly different between applications of the shrimp waste and applications of the inorganic nutrients (Tables 48 and 49).

Summary and Conclusions

Shrimp processing waste was equivalent to conventional inorganic materials as a source of N and P for the growth of orchardgrass.

Table 48. The effect of shrimp waste and inorganic sources of nitrogen and phosphorus on orchardgrass yield, nitrogen uptake, and phosphorus uptake. A summary of the analysis of variance.

Source of Variation	Degrees of Freedom	Cumulative Yield	N uptake	P uptake
		Significance level of F value		
Fertilizer (shrimp waste and inorganic)	1	**	NS	**
Nitrogen	1	**	**	**
Phosphorus	1	**	NS	**
Fertilizer x Nitorgen	1	*	NS	NS
Fertilizer x Phosphorus	1	NS	NS	NS
Nitrogen x Phosphorus	1	**	*	NS
Fertilizer x Nitrogen x Phosphorus	1	NS	NS	NS
		Mean Square		
Error	21	0.134	78.399	0.639

Table 49. Treatment means[1] for yield, nitrogen uptake, and phosphorus uptake by orchardgrass.

	Fertilizer	N_1		N_2	
		P_1	P_2	P_1	P_2
		g/pot			
Yield	Shrimp waste	6.20	6.56	8.90	10.02
	Inorganic	5.96	6.55	8.11	9.44
		mg/pot			
N uptake	Shrimp waste	133.51	130.40	224.71	239.40
	Inorganic	138.95	132.05	224.49	228.12
P uptake	Shrimp waste	9.61	13.20	12.11	15.77
	Inorganic	8.09	11.98	9.94	13.27

[1] Average of four replications.

FIELD EXPERIMENT

Introduction

This experiment was established to compare the effects of three application rates of shrimp processing wastes and two, typical application rates of ammonium phosphate (16-20-0-15S) on an irrigated coastal pasture.

Materials and Methods

Treatments

The treatments (Tables 50 and 51) were arranged in the field in a randomized complete block design with four replications. Each replicate occupied a plot 152 cm by 244 cm (five feet by eight feet).

Table 50. Shrimp waste and commercial fertilizer application rates.

Fertilizer	Application Rate		
	-kg/ha-	tons/acre	pounds/acre
Control	0	0	0
Shrimp waste[1]	6,726	3	--
	17,936	8	--
	35,872	16	--
Ammonium phosphate	224.2	--	200
	448.4	--	400

[1] 78% moisture.

Table 51. Rates of nitrogen, phosphorus, and sulfur supplied by the shrimp waste and the commercial fertilizer.

Fertilizer	Fertilizer Rate	N	P	S
	----------kg/ha----------			
Control	0	0	0	0
Shrimp waste[1]	6,726	86.27	31.81	4.14
	17,936	230.05	84.84	11.05
	35,872	460.09	169.67	22.10
Ammonium phosphate	224.2	35.87	19.73	33.63
	448.4	71.74	39.46	67.26

[1] 78% moisture.

FIELD TRIAL

Fertilizer Materials

Shrimp processing waste was obtained from the New England Fish Company, Newport, Oregon and was hand applied to the plots within two to three hours of collection.

Commercial grade ammonium phosphate sulfate (16-20-0 15S) was used.

Soil and Experimental Site

The experiment was established on a Nehalem silt loam soil (Table 52). The experimental site was an old subclover (*Trifolium subterraneum* L.), perennial ryegrass (*Lolium perenne* L.), and orchardgrass pasture (NW 1/4 Sec. 4, T.11S., R. 10 W.) which had been plowed the preceeding fall. The site was located on the farm of John Dickenson in Lincoln County.

Procedure

An application of finely ground limestone equivalent to 8968 kg lime/ha (4 T/A) was evenly applied by hand to the experimental area and mixed into the soil with a rototiller. After the lime was incorporated, the ammonium phosphate and the shrimp waste was evenly applied by hand to the appropriate plots and mixed into the soil with a rototiller. The experimental area was seeded by hand at twice the recommended seed application rates with orchardgrass (Dactylis glomerata L.) 'Potomac', tall fescue (Festuca arundinacea Schreb.) 'Fawn', and inoculated New Zealand white clover (Trifolium repens L.) on April 29, 1976. The soil was raked, and packed with a lawn roller. The area was weeded once, by hand, on June 16, 1976. A good stand of grass and clover was established. The plots were sprinkler irrigated occasionally to supplement rainfall. The forage was harvested on June 29, July 7, August 19, September 10, and October 12, 1976, for a total growing period of 5.5 months. The grass often reached a height of 30 to 35 cm between harvests, and by the second harvest orchardgrass had become the dominant species on all plots. Prior to harvesting, 45 cm was cut from the end of each plot. A 91 cm swath, 152 cm long was cut from the middle

Table 52. Soil chemical analysis of Nehalem silt loam.

Depth	pH	SMP	P	K	B	Ca	Mg	Total-N	OM
cm			------ppm--------			--meq/100g---		--------%------	
0-15	4.9	5.6	22	262	0.58	12.2	5.5	0.34	7.3
15-60	4.8	5.2	11	216	0.47	9.3	4.4	----	----

of each plot with a sickle-bar mower and immediately weighed. The grass was cut to a height of 3 to 4 cm. Sub-samples were retained from each plot for dry matter determination and analyses. Samples were oven dried at 65 $^{\circ}$C, ground in a Wiley mill, and assayed for P and N concentrations (Table 12).

Statistical Analysis

Cumulative yields for each fertilizer treatment were compared using Duncan's new multiple range test. When appropriate, LSD and $S_{\bar{x}}$ are presented.

All data are listed in Appendix Tables 10, 11, and 12.

Results and Discussion

The shrimp waste was incorporated with the soil before the forage crop was planted, but after the first rain, about 20% to 40% of the shrimp waste remained on the soil surface. No surface movement of the shrimp waste occurred. By the end of the experimental period (after 5.5 months) very little shell material could be found in the experimental area.

By the second harvest, orchardgrass was the dominant forage species. The grass often reached a height of 30 to 40 cm between harvests, and most of the white clover was lost on all plots.

All fertilizer treatments resulted in significantly higher forage yields than the control (Table 53). Forage yields increased as shrimp waste applications increased to 17,936 kg/ha (8 T/A), but waste applications beyond this rate did not further increase the yield (Table 53). When comparable rates of N and P were supplied by the fertilizer materials (shrimp waste at 6,726 kg/ha and ammonium phosphate at 448 kg/ha), the forage yield was slightly (but not significantly) higher with the shrimp waste (Tables 51 and 53).

Table 53. Cumulative forage yields from applications of shrimp waste and a commercial fertilizer.

Fertilizer	Fertilizer Rate	Cumulative Yield (dry matter)	
	----kg/ha----	-g/plot-	tons/acre
Control	0	1059 a[1]	3.39
Shrimp waste	6,726	1532 b	5.21
	17,936	1903 c	6.09
	35,872	1915 c	6.13
Ammonium phosphate	224	1346 b	4.31
	448	1495 b	4.77
		$LSD_{.01}$ = 290.8	
		$LSD_{.05}$ = 210.3	
		$S_{\overline{x}}$ = 69.8	

[1] Means that do not have a letter in common differ significantly at the 5% level of probability by Duncan's new multiple range test.

All application rates of shrimp waste significantly increased the N concentration in the forage over the control through harvest period three (Table 54). The higher application rates of shrimp waste significantly increased the forage N concentration over the control in every harvest period. Applications of ammonium phosphate significantly increased the forage N concentration in the first harvest period only. The forage N concentration was slightly higher with the lowest shrimp waste application rate than with the highest ammonium phosphate application rate at each harvest period (Table 54).

None of the forage P concentration means for the fertilizer treatments were significantly higher than the control (Table 55). All forage P concentration means (except 0.19%) were within or above the critical P concentration range for orchardgrass, the level at which no substantial P response would be expected (Martin and Matocha 1973). It appears that the P supplying power of the soil was high. A dilution effect on the forage P concentration was evident with the higher rates of the fertilizer materials at the later harvest periods (Table 55). Although fertilizer applications did not increase the P concentration in the forage, fertilizer applications resulted in a greater P uptake by the forage (Table 56).

Table 54. Forage nitrogen concentrations at each harvest period with applications of shrimp waste and a commercial fertilizer.

Fertilizer	Fertilizer Rate	Harvest 1	2	3	4	5
	--kg/ha--	---------------%N---------------				
Control	0	3.32	2.93	2.68	2.84	3.16
Shrimp waste	6,726	4.46	3.70	3.34	3.30	3.08
	17,936	4.60	3.90	3.96	4.22	3.72
	35,872	4.91	3.80	4.16	4.34	4.12
Ammonium phosphate	224	4.05	3.12	2.92	3.39	3.38
	448	4.07	3.29	2.87	3.24	3.06

$LSD_{.01} = 0.647$, $S_{\bar{x}} = 0.173$

Table 55. Forage phosphorus concentrations at each harvest period with applications of shrimp waste and a commercial fertilizer.

Fertilizer	Fertilizer Rate	Harvest 1	2	3	4	5
	--kg/ha--	---------------%P---------------				
Control	0	.20	.24	.41	.43	.51
Shrimp waste	6,726	.21	.21	.36	.39	.45
	17,936	.21	.22	.34	.29	.33
	35,872	.21	.23	.36	.29	.31
Ammonium phosphate	224	.21	.23	.39	.42	.56
	448	.19	.22	.34	.37	.44

$LSD_{.01} = 0.65$, $S_{\bar{x}} = .017$

Table 56. Cumulative phosphorus uptake by orchardgrass from applications of shrimp waste and a commercial fertilizer.

Fertilizer	Fertilizer Rate	Cumulative P Uptake
	------kg/ha----	---------g/plot------
Control	0	3.29
Shrimp waste	6,726	4.50
	17,936	5.25
	35,872	5.23
Ammonium phosphate	224	4.01
	448	4.00

When comparable rates of N and P were supplied by the fertilizer materials, the P uptake by the forage was higher from the shrimp waste than from the ammonium phosphate (Tables 51 and 56). Phosphorus uptake by the forage increased as shrimp waste applications increased to 17,936 kg/ha (8 T/A), but waste applications beyond this rate did not further increase the forage P uptake (Table 56).

In comparison to the control, no consistent, measurable increase in soil pH, extractable Ca, or extractable Mg occurred from shrimp waste application (Table 57), but the effect of the shrimp waste on these soil characteristics might have been masked by the limestone application. All fertilizer treatments increased the extractable soil P over the control (Table 57). At the 0-15 cm depth, increasing rates of shrimp waste application increased the

Table 57. Soil chemical analysis of Nehalem silt loam treated with shrimp waste and a commercial fertilizer in a coastal pasture.[1]

Treatment	(kg/ha)	pH		P (ppm)		K (ppm)		Ca (meq/100g)		Mg (meq/100g)		Soluble Salts (mmhos/cm)		SO_4-S (ppm)		NO_3-N (ppm)	
		Depth (cm)															
		0-15	15-60	0-15	15-60	0-15	15-60	0-15	15-60	0-15	15-60	0-15	15-60	0-15	15-60	0-15	15-60
Control		6.0	5.2	18	8	184	163	16.9	8.7	5.2	4.0	.35	.14	11.8	6.2	11.4	6.1
Shrimp Waste	6,726	6.1	5.2	22	10	190	200	18.5	8.4	5.3	4.2	.36	.14	7.8	1.8	11.4	7.7
	17,936	6.1	5.1	25	10	149	146	18.5	9.1	5.1	4.2	.58	.20	14.6	5.4	38.9	10.8
	35,872	5.9	5.0	28	10	154	158	18.1	9.5	5.0	4.1	1.01	.43	15.2	5.6	68.8	33.2
Ammonium phosphate	224	6.0	5.2	22	10	183	157	17.6	9.7	5.3	4.4	.46	.18	18.4	3.6	16.8	8.5
	448	6.0	5.2	23	10	194	197	17.4	10.3	5.1	4.8	.48	.19	26.2	7.0	13.5	6.0

[1] Sampled after last forage harvest (October 12, 1976) average of two analyses, each analysis was performed on a composite of two replicates (Table 11).

extractable soil P. The two highest rates of shrimp waste application gave the largest forage yields, and resulted in a substantial decrease in the extractable soil K in the top 0-15 cm (Table 57). A net depletion of soil K reserves with applications of shrimp waste is indicated. Shrimp waste applications of 35, 872 kg/ha (16 T/A) resulted in a three-fold increase in soluble salts over the control to a depth of 60 cm (Table 57). No evidence of salt damage to the forage plants was observed, and salt accumulation is unlikely under conditions of high rainfall. With increasing rates of S supplied by all fertilizer treatments (except the lowest shrimp waste application rate), extractable soil SO_4-S increased in the top 15 cm (Table 57). Shrimp waste applications of 35, 872 kg/ha (16 T/A) increased soil NO_3-N values six-fold, and shrimp waste applications of 17, 936 kg/ha (8 T/A) increased soil NO_3-N values three-fold over the control to depths of 60 cm and 15 cm respectively (Table 57). In the top 15 cm of the soil, 68.8 ppm and 38.9 ppm of NO_3-N was measured with the highest and second highest rates of shrimp waste applications respectively, after an equivalent of 13, 440 kg of grass forage (dry matter)/ha (6 T/A) was removed from each treatment area.

Shrimp waste applications beyond 17, 936 kg/ha (8 T/A) did not further increase forage yields, and the N supplied was not efficiently utilized by the grass forage. Excessive N application rates can result in potentially toxic levels of NO_3-N in grass forage (George *et al.* 1973). Residual soil NO_3-N at the end of the growing season can be a source for groundwater contamination when rain water percolates through the soil (Zwerman *et al.* 1972).

Summary and Conclusions

When comparable rates of N and P were supplied by shrimp processing waste and ammonium phosphate (16-20-0 15S) to a stand of orchardgrass in an irrigated coastal pasture, the forage yield, the N concentration in the grass, and the P uptake by the grass were higher with applications of the shrimp waste than with applications of the ammonium phosphate.

Applications of shrimp waste beyond 8 T/A did not further increase forage yield or P uptake by the grass. A forage yield equivalent to 6 T/A (dry matter), a respectable yield for a well managed irrigated coastal pasture, was obtained with shrimp waste applications of 8 T/A, however, an equivalent of 78 lbs NO_3-N/ha remained in the top six inches of the soil at the end of the growing season. Under conditions of high winter rainfall, residual N would be lost by leaching or denitrification.

For efficient utilization of applied N on stands of grass forage (not including vigorous grass-clover mixtures) in the coastal area, shrimp and crab waste applications should not exceed 8 to 10 T/A per year.

RECOMMENDATIONS

Shrimp and crab processing solid wastes contain significant amounts of N and P (Table 9) in forms which become available for crop growth when the wastes are applied as fertilizer materials. The monetary value of the N and P contained in shrimp and crab processing wastes is equivalent to the monetary value of the N and P from conventional, commercial fertilizers. Some additional monetary value can be attributed to the Ca, K, Mg, S, other plant nutrients, and lime contained in the wastes. The actual worth of any fertilizer material depends not only on the effectiveness and cost, but also on the amount of time and equipment required to transport, handle, and apply the material. The low density of the wastes and the large amount of associated water limits the distance that the wastes can be economically transported.

Shrimp waste is generated in April through October when fields are accessible and crop nutrient requirements are high. Most of the crab waste is generated in December through May when access to fields is often limited, crop nutrient requirements are generally low, and a loss of soluble nutrients from the applied wastes can occur. If economically feasible, preserving crab waste by drying, composting, or other methods, could be beneficial.

The wastes can be applied as they come from the processing plants with no further treatment. Dry manure spreaders can be used to apply the wastes without modification. Shrimp and crab wastes should be incorporated with the soil for new plantings, but the wastes can be left on the soil surface of established pastures with good results. When crab wastes are left on the soil surface, crop response will be increased by breaking the large shells and putting them into close contact with the soil surface. Methods of breaking the shells could include the action of grazing animals or light cultivation. Grazing animals are not bothered by surface applied shrimp and crab wastes after rain or irrigation water has washed the waste material off the forage plants. Odor and insect problems can be kept at a minimum if shrimp and crab wastes are spread in the fields as soon after processing as possible.

On forages and other crops, shrimp and crab wastes should be applied at rates necessary to supply the recommended rates of N. A ton of fresh waste will supply approximately 25 and 32 pounds of N for shrimp and crab wastes respectively. The rates of P, S, other nutrients, and lime supplied by the waste application should be calculated, and supplemental fertilizers should be applied if required. Crop nutrient needs can be determined by soil analysis and, in Oregon, OSU Extension fertilizer guide sheets. The ratio of N to P in shrimp and crab processing, solid wastes is approximately 3:1.

Phosphorus requirements will generally be satisfied with moderate waste applications. The use of shrimp and crab wastes will result in depletion of soil K by crop plants. Soils should be tested annually to monitor K levels and K fertilizers should be applied to supplement waste applications on soils with low levels of K. Liquid manure applications can supply significant amounts of K.

The supply of N is a major limiting factor in the growth of grasses. Two management alternatives are available to supply N to forage stands. Forage grasses can be grown in association with legumes. The establishment and maintenance of a vigorous clover component in grass-clover mixtures in Oregon coastal pastures generally requires a well-drained soil, the liming of acid soils, and regular applications of P, K, and S. Alternatively, fertilizers or manure can be applied to supply N to stands of grass forage. Forage grasses are generally more tolerant of acid soil conditions than are forage clovers, and certain grass species, particularly reed canarygrass (*Phalaris arundinaceae* L.), are successfully grown in poorly drained or periodically flooded areas.

The addition of fertilizer N to grass-clover mixtures favors the growth of grass over the growth of clover. Excessive fertilization with N will generally result in a grass dominant pasture. Careful management is required to prevent a decrease in the clover stand. Frequent clipping or close grazing will reduce the loss of clover. When forage legumes are actively growing, the addition of fertilizer N will reduce the amount of N fixed by the legume and no net gain in protein production will occur. Waste applications of 1 to 1.5 T/A on grass-clover mixtures in late February through early March, when clover growth is slow, will stimulate the grass and provide early feed. Waste applications in late August on grass-clover mixtures will stimulate grass growth and provide additional fall grazing. On grass-clover mixtures, if single waste applications exceed 1.5 T/A or if annual waste applications exceed 3 T/A, the stand should be carefully managed to prevent the loss of clover, or should be managed as a pure stand of grass.

On stands of grass forage, waste applications at rates in the range of 1 to 10 T/A per year are recommended. Waste applications in excess of 8 to 10 T/A per year are not recommended because applied N is not used efficiently and NO_3-N contamination of groundwater can occur with high application rates. Waste applications on stands of improved grasses such as orchardgrass, perennial ryegrass, or tall fescue will result in greater yield increases than waste applications on pastures dominated by weedy or unimproved grass species.

Annual waste applications over a period of years should decrease soil acidity and build soil P and Ca levels. Additional research to determine the long-term liming effect of annual waste applications could benefit coastal farmers because of the high costs associated with conventional liming practices.

Some valuable insights might be obtained by a detailed examination of the mechanisms by which applications of shrimp and crab processing wastes to an acid soil enhanced the P availability, the growth of a legume sensitive to acid soils, and the activity of an acid sensitive rhizobial bacteria, without measurably increasing the pH of the total soil mass.

Results of the greenhouse experiments indicate that, with careful management, it may be possible to maintain a vigorous grass-clover mixture on acid coastal soils with annual applications of shrimp or crab processing wastes at rates of 2 to 6 T/A without the necessity of costly liming. Additional field research is necessary to corroborate the greenhouse findings and to determine management practices required to maintain the clover component in these pastures.

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APPENDIX

Appendix Table 1a. Orchardgrass yields. Greenhouse experiment I.

Treatment Number[1]	Replication	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Treatment Number	Replication	Harvest 1	Harvest 2	Harvest 3	Harvest 4
		g/pot						g/pot			
1	1	1.16	2.75	0.98	0.42	17	1	1.90	6.06	2.22	0.45
	2	1.47	2.46	0.71	0.52		2	1.94	6.62	1.96	0.59
	3	1.17	2.50	0.59	0.62		3	1.93	6.54	1.79	0.45
2	1	0.65	1.91	0.96	0.44	18	1	1.39	4.63	2.01	0.68
	2	1.28	2.02	0.56	0.65		2	1.41	3.93	1.36	0.54
	3	0.84	2.17	0.80	0.62		3	1.59	4.48	1.63	0.75
5	1	0.24	1.43	3.17	2.24	21	1	1.11	3.49	5.48	1.68
	2	0.54	2.45	4.19	0.62		2	1.10	4.93	5.54	1.77
	3	0.45	2.38	3.32	1.41		3	0.96	4.35	6.14	1.57
6	1	0.06	0.66	1.72	3.15	22	1	0.73	2.54	3.69	1.45
	2	0.27	1.28	2.35	2.16		2	0.66	3.27	4.52	1.12
	3	0.18	1.05	1.98	1.82		3	0.77	2.21	3.51	2.57
9	1	1.39	3.48	1.62	0.45	37	1	0.38	2.34	3.42	0.57
	2	1.66	4.30	1.29	0.44		2	0.40	2.11	2.92	0.65
	3	1.36	4.12	1.16	0.51		3	0.38	1.97	3.22	0.62
10	1	1.12	2.93	1.38	0.57	38	1	0.48	1.77	1.70	0.42
	2	1.34	2.48	1.02	0.53		2	0.47	1.56	2.09	0.46
	3	1.31	3.94	2.01	0.84		3	0.33	1.60	2.84	0.62
13	1	0.54	2.66	5.13	1.39	41	1	0.68	3.51	4.77	0.81
	2	0.82	3.82	4.95	0.87		2	0.53	2.75	4.00	1.09
	3	0.51	2.34	3.94	3.68		3	0.62	2.73	4.21	0.76
14	1	0.19	1.68	3.76	1.47	42	1	0.85	2.61	2.50	0.49
	2	0.40	1.88	3.68	1.35		2	0.72	3.00	3.25	0.91
	3	0.69	2.28	4.04	1.08		3	0.39	2.19	3.59	0.66

[1] Table 8, page 46.

Appendix Table 1a. Continued

Treatment Number	Replication	Harvest 1	2	3	4	Treatment Number	Replication	Harvest 1	2	3	4
		g/pot						g/pot			
45	1	0.91	3.92	5.67	1.17	62	1	0.26	1.38	2.81	0.76
	2	0.96	4.25	4.97	1.03		2	0.37	1.63	2.69	0.78
	3	0.85	3.56	4.82	1.22		3	0.28	1.13	2.02	1.80
46	1	1.16	3.16	4.77	0.96	65	1	1.18	1.72	0.56	0.49
	2	1.32	3.11	2.58	0.44		2	1.04	2.16	0.64	0.29
	3	1.35	4.55	2.06	0.60		3	1.07	2.46	0.97	0.60
49	1	0.56	2.18	3.82	0.69	66	1	1.29	1.65	0.82	0.49
	2	0.60	2.11	3.01	0.64		2	1.13	2.04	0.67	0.51
	3	0.24	1.25	1.90	2.53		3	0.77	2.02	1.10	0.51
50	1	0.14	0.79	1.64	2.63	69	1	0.64	3.38	4.45	0.84
	2	0.28	1.01	1.81	1.26		2	0.74	4.23	3.56	0.41
	3	0.22	0.94	1.40	2.09		3	0.43	2.98	4.91	1.10
53	1	0.23	1.96	4.19	1.66	70	1	0.12	1.05	2.68	1.11
	2	0.15	1.77	4.62	1.50		2	0.29	1.52	2.93	1.34
	3	0.24	2.22	5.09	2.02		3	0.36	1.64	2.65	1.40
54	1	0.14	0.80	1.95	1.70	73	1	0.75	2.94	1.76	0.52
	2	0.21	1.47	2.81	0.82		2	1.13	3.16	1.11	0.65
	3	0.20	0.97	2.09	1.65		3	1.04	3.37	1.57	0.37
57	1	0.37	2.70	5.07	1.19	74	1	0.96	2.60	1.17	0.55
	2	0.85	4.08	4.90	0.93		2	0.92	2.60	0.98	0.48
	3	0.40	2.97	5.36	1.75		3	1.06	3.03	1.46	0.60
58	1	0.23	1.31	2.12	2.74	77	1	0.73	3.75	6.82	1.54
	2	0.21	1.24	2.22	1.58		2	0.89	5.02	5.56	0.94
	3	0.35	1.32	2.07	2.68		3	0.65	3.55	5.87	2.76
61	1	0.19	1.40	3.69	0.96	78	1	0.15	1.17	3.01	3.10
	2	0.21	1.26	2.44	0.95		2	0.47	2.51	4.00	1.49
	3	0.37	1.69	2.92	0.84		3	0.36	2.12	4.12	2.86

Appendix Table 1a. Continued

Treatment Number	Replication	Harvest 1	2	3	4	Treatment Number	Replication	Harvest 1	2	3	4
		g/pot						g/pot			
81	1	1.00	4.10	2.84	0.70	98	1	0.98	1.47	0.66	0.60
	2	1.76	5.06	1.65	0.45		2	1.02	1.66	0.76	0.69
	3	1.25	3.61	2.80	0.99		3	0.76	1.64	0.81	0.66
82	1	0.85	3.26	2.06	0.64	101	1	0.12	0.73	1.28	1.95
	2	1.34	4.27	1.57	0.51		2	0.12	0.86	1.80	1.40
	3	0.88	3.48	1.16	0.52		3	0.16	0.86	1.67	1.87
85	1	0.47	2.53	4.44	0.86	102	1	0.10	0.70	1.57	2.05
	2	0.54	2.64	3.87	0.80		2	0.20	0.84	1.84	1.42
	3	0.45	2.05	3.63	1.19		3	0.16	0.82	1.52	2.40
86	1	0.22	1.42	3.04	0.59	105	1	1.23	2.97	1.39	0.60
	2	0.39	1.86	2.71	0.54		2	1.70	2.53	1.20	0.66
	3	0.24	1.42	2.78	2.03		3	1.50	2.78	1.07	0.62
89	1	0.74	3.29	2.62	0.64	106	1	1.35	2.96	1.10	0.65
	2	0.78	3.85	2.91	0.52		2	1.07	3.07	1.29	0.54
	3	0.60	2.92	4.13	1.10		3	1.14	2.68	0.88	0.52
90	1	0.41	2.20	4.53	0.91	109	1	0.97	3.32	3.11	0.79
	2	0.60	1.90	2.81	0.43		2	1.16	4.76	1.89	0.58
	3	0.64	1.94	2.97	0.52		3	0.85	3.25	3.22	0.78
93	1	0.95	5.34	4.84	0.92	110	1	0.88	3.63	3.04	0.86
	2	1.18	5.93	3.74	0.55		2	1.20	4.02	2.34	0.64
	3	0.74	3.95	6.69	1.90		3	0.86	3.16	3.43	0.81
94	1	0.80	2.43	4.12	0.91	113	1	1.30	4.51	1.71	0.56
	2	0.70	3.50	4.69	1.07		2	1.29	4.10	1.47	0.42
	3	0.82	2.97	3.65	1.19		3	1.30	4.35	2.23	0.88
97	1	0.76	1.79	0.95	0.54	114	1	1.69	3.82	1.92	0.68
	2	1.14	1.64	0.87	0.58		2	1.59	4.47	1.53	0.55
	3	0.94	1.64	0.73	0.54		3	1.30	3.98	2.12	0.74

Appendix Table 1a. Continued

Treatment Number	Replication	Harvest 1	2	3	4
		-------------	g/pot	-------------	
117	1	0.83	3.57	4.11	1.19
	2	1.08	4.67	4.25	0.88
	3	0.78	2.76	4.39	2.18
118	1	0.75	3.36	3.90	1.58
	2	0.94	4.19	4.41	1.06
	3	0.74	3.12	5.45	1.81
121	1	1.23	4.69	4.31	0.58
	2	1.24	5.09	5.27	0.74
	3	0.87	4.31	3.75	0.81
122	1	1.11	3.58	5.72	1.16
	2	1.43	5.18	3.62	0.58
	3	1.26	4.99	4.62	0.80
125	1	0.86	3.42	6.75	2.40
	2	0.98	3.81	4.43	1.31
	3	0.81	2.84	4.91	3.62
126	1	0.76	3.43	5.46	2.64
	2	1.02	4.78	5.42	1.49
	3	0.60	2.81	4.42	3.92

Appendix Table 1b. Orchardgrass - white clover association yields. Greenhouse experiment I.

Treatment[2] Number	Replication	Harvest 1 G[1]	1 C	2 G	2 C	3 G	3 C	4 G	4 C	5 G	5 C	6 G	6 C
		g/pot											
3	1	0.77	0.39	1.77	0.83	0.65	1.88	0.20	3.82	0.02	6.86	0.04	9.36
	2	0.97	0.35	1.23	0.71	0.64	1.57	0.20	4.32	0.10	10.84	0.16	5.46
	3	0.87	0.35	1.77	0.37	0.59	1.26	0.21	4.24	0.06	7.56	0.01	7.44
4	1	0.57	0.32	1.37	0.57	0.79	1.27	0.29	3.49	0.14	6.45	0.26	9.55
	2	0.90	0.33	1.34	0.47	0.73	1.60	0.27	3.64	0.04	13.20	0.01	5.56
	3	0.56	0.33	1.64	0.56	0.89	0.93	0.45	2.63	0.15	7.64	0.01	9.72
7	1	0.14	0.10	0.96	0.32	2.20	1.01	1.07	0.90	0.29	0.76	0.22	2.21
	2	0.18	0.10	1.14	0.49	2.10	1.29	0.51	0.64	0.12	0.90	0.15	2.85
	3	0.27	0.07	1.26	0.31	2.61	0.91	0.87	0.43	0.21	0.72	0.17	1.63
8	1	0.13	0.05	0.72	0.31	1.78	0.76	0.96	0.67	0.25	0.31	0.32	0.46
	2	0.22	0.08	0.93	0.27	0.87	0.73	0.48	0.52	0.21	0.78	0.23	0.97
	3	0.13	0.06	0.62	0.30	1.10	0.67	0.90	0.46	0.17	0.70	0.10	1.38
11	1	0.64	0.40	1.93	0.61	2.11	1.70	0.40	4.13	0.10	8.65	0.01	15.56
	2	1.10	0.40	2.22	0.76	0.76	1.77	0.27	4.21	0.09	11.09	0.36	4.05
	3	0.89	0.37	2.90	1.05	1.01	1.77	0.18	4.68	0.04	8.97	0.02	7.70
12	1	0.67	0.43	1.94	1.14	1.11	1.78	0.35	3.27	0.28	7.41	0.69	6.05
	2	0.95	0.39	2.55	1.92	1.22	1.98	0.33	3.82	0.09	8.98	0.45	5.30
	3	0.58	0.33	1.77	0.87	1.04	1.73	0.36	4.30	0.23	10.60	0.10	6.38
15	1	0.42	0.10	1.96	0.27	3.61	0.69	1.22	0.65	0.33	0.56	0.32	1.78
	2	0.56	0.15	2.99	0.53	4.00	0.85	0.85	0.79	0.26	1.93	0.17	2.49
	3	0.50	0.15	2.15	0.44	3.33	0.92	0.83	1.07	0.15	1.31	0.18	2.28
16	1	0.41	0.10	1.66	0.47	2.68	1.18	0.56	1.29	0.33	1.81	0.16	2.56
	2	0.38	0.07	1.41	0.34	2.63	0.71	0.75	0.17	0.29	0.13	0.63	0.29
	3	0.27	0.10	1.55	0.41	2.23	1.05	0.69	0.52	0.31	0.85	0.16	1.47

[1] G = Orchardgrass C = White Clover

[2] Table 8, page 46.

Appendix Table 1b. Continued

Treatment Number	Replication	Harvest 1		2		3		4		5		6	
		G[1]	C	G	C	G	C	G	C	G	C	G	C
		g/pot											
19	1	0.74	0.51	3.21	1.13	2.80	1.40	0.32	2.84	0.18	6.43	0.20	11.72
	2	1.23	0.32	4.14	0.79	2.52	0.96	0.65	2.54	0.63	8.18	0.50	8.84
	3	0.91	0.39	4.79	0.54	2.10	0.53	0.41	2.11	0.13	9.72	0.05	12.93
20	1	0.95	0.57	2.76	1.31	1.19	2.60	0.43	6.69	0.14	11.54	0.14	12.96
	2	1.04	0.40	2.87	0.73	1.36	1.00	0.60	3.67	0.40	12.13	0.36	11.24
	3	1.06	0.50	3.38	1.37	1.42	2.06	0.42	5.61	0.39	13.66	0.57	6.63
23	1	0.46	0.13	3.05	0.49	4.66	0.95	1.14	1.32	0.22	1.03	0.27	2.14
	2	0.72	0.22	3.40	0.66	4.88	0.78	0.90	1.10	0.16	2.59	0.16	2.61
	3	0.40	0.13	1.68	0.23	3.26	0.68	4.67	0.99	0.89	1.12	0.21	2.24
24	1	0.58	0.05	2.75	0.47	5.13	0.91	1.32	1.07	0.82	1.22	0.56	1.20
	2	0.42	0.12	2.51	0.53	3.99	1.07	1.19	0.81	0.44	1.53	0.33	3.12
	3	0.62	0.11	2.55	0.24	1.54	0.42	0.64	1.13	0.32	3.00	0.23	5.70
39	1	0.11	0.07	0.83	0.56	1.39	0.92	0.30	0.52	0.11	0.22	0.12	0.84
	2	0.24	0.11	1.14	0.48	1.64	0.91	0.26	0.23	0.27	0.18	0.49	0.34
	3	0.16	0.07	0.91	0.31	1.88	1.10	0.50	0.63	0.07	0.88	0.01	1.02
40	1	0.11	0.08	0.70	0.32	2.07	0.93	0.49	0.89	0.14	1.28	0.03	2.96
	2	0.16	0.07	1.06	0.42	2.08	1.58	0.40	0.56	0.26	1.10	0.31	1.22
	3	0.17	0.09	1.09	0.35	1.92	0.97	0.65	0.89	0.20	1.20	0.06	2.54
43	1	0.42	0.14	1.68	0.61	2.61	1.75	0.37	1.02	0.09	1.19	0.01	1.22
	2	0.30	0.13	1.85	0.53	2.75	1.58	0.59	0.43	0.14	0.86	0.44	0.98
	3	0.30	0.13	1.80	0.42	3.24	1.19	0.88	0.70	0.17	1.46	0.15	1.95
44	1	0.35	0.04	1.68	0.31	2.57	1.00	0.41	1.23	0.28	1.85	0.07	2.22
	2	0.67	0.11	2.77	0.49	2.44	0.68	0.42	0.36	0.29	1.14	0.38	0.87
	3	0.35	0.08	2.48	0.56	2.85	0.85	0.58	0.45	0.33	1.89	0.08	2.51

Appendix Table 1b. Continued

Treatment Number	Replication	Harvest 1 G[1]	Harvest 1 C	Harvest 2 G	Harvest 2 C	Harvest 3 G	Harvest 3 C	Harvest 4 G	Harvest 4 C	Harvest 5 G	Harvest 5 C	Harvest 6 G	Harvest 6 C
		g/pot											
47	1	0.45	0.16	2.78	0.61	4.82	1.27	1.14	1.00	0.26	0.72	0.19	2.01
	2	0.41	0.16	2.61	0.58	3.79	1.20	1.27	1.15	0.32	1.22	0.30	2.15
	3	0.45	0.12	1.99	0.22	4.56	0.42	3.32	0.35	0.20	1.13	0.06	3.97
48	1	0.71	0.08	3.57	0.46	2.53	0.52	0.65	0.99	0.36	0.55	0.41	0.68
	2	0.56	0.05	2.77	0.31	4.63	0.61	0.85	0.95	0.16	1.38	0.29	1.78
	3	0.69	0.12	3.13	0.57	3.32	0.88	0.49	1.12	0.40	2.85	0.65	1.67
51	1	0.20	0.05	1.22	0.37	2.25	1.35	0.49	1.72	0.14	1.96	0.06	1.32
	2	0.15	0.07	1.12	0.32	2.13	1.10	0.97	1.11	0.21	1.07	0.25	0.72
	3	0.29	0.06	1.28	0.21	2.22	0.91	1.55	0.91	0.35	0.65	0.29	0.18
52	1	0.11	0.04	0.65	0.24	1.26	0.63	0.56	0.38	0.17	0.25	0.16	0.62
	2	0.09	0.07	0.69	0.29	1.46	1.08	0.31	0.42	0.16	0.46	0.46	0.60
	3	0.11	0.09	0.39	0.24	0.72	0.64	0.90	0.34	0.17	0.11	0.29	0.18
55	1	0.16	0.05	1.36	0.35	4.22	1.01	0.80	0.62	0.36	0.88	0.24	1.88
	2	0.15	0.10	1.47	0.65	3.23	1.65	0.46	1.24	0.28	0.46	0.78	0.66
	3	0.09	0.06	0.94	0.29	2.18	1.49	1.30	1.96	0.16	2.55	0.09	3.64
56	1	0.12	0.06	0.63	0.28	1.31	0.91	0.83	0.70	0.33	0.27	0.27	1.35
	2	0.10	0.05	0.63	0.27	1.44	0.59	0.93	0.11	0.36	0.20	0.40	0.36
	3	0.17	0.09	0.84	0.23	1.24	0.68	1.45	0.88	0.30	0.46	0.25	0.85
59	1	0.37	0.04	2.26	0.50	4.88	1.25	1.23	2.00	0.38	2.75	0.23	3.89
	2	0.26	0.09	3.16	0.51	3.68	1.10	0.69	2.06	0.22	1.56	0.87	1.64
	3	0.21	0.05	2.07	0.28	4.01	0.85	1.72	1.78	0.26	2.64	0.24	3.62
60	1	0.13	0.05	0.68	0.33	1.79	0.87	1.03	0.86	0.50	1.00	0.24	1.55
	2	0.10	0.07	0.91	0.32	1.68	0.95	1.12	0.63	0.37	0.56	0.51	1.06
	3	0.10	0.10	0.73	0.36	1.48	1.25	0.68	0.83	0.26	0.93	0.48	1.74

Appendix Table 1b. Continued

Treatment Number	Replication	Harvest 1		2		3		4		5		6	
		G[1]	C	G	C	G	C	G	C	G	C	G	C
		g/pot											
63	1	0.16	0.06	1.24	0.38	2.48	1.02	0.47	0.88	0.10	1.16	0.09	2.09
	2	0.17	0.06	1.09	0.24	2.21	0.64	0.72	0.31	0.20	0.53	0.50	0.57
	3	0.19	0.09	1.22	0.30	2.19	0.95	0.37	0.80	0.08	2.14	0.01	3.40
64	1	0.05	0.04	0.63	0.26	1.60	0.75	0.51	0.35	0.20	0.70	0.08	1.28
	2	0.12	0.09	0.90	0.55	1.50	1.13	0.33	0.24	0.24	0.20	0.51	0.56
	3	0.13	0.11	0.71	0.27	1.53	0.58	0.67	0.19	0.14	0.70	0.01	2.42
67	1	0.68	0.40	1.35	0.65	0.68	1.95	0.23	4.63	0.01	8.27	0.04	12.84
	2	0.81	0.41	1.52	1.03	0.74	0.90	0.27	4.46	0.11	8.53	0.14	8.23
	3	0.67	0.34	1.34	0.75	0.68	1.72	0.27	4.62	0.08	7.93	0.04	5.37
68	1	0.61	0.27	1.37	0.64	0.77	1.65	0.37	3.13	0.54	4.36	0.45	5.26
	2	0.82	0.38	1.40	0.58	0.75	0.90	0.27	3.04	0.10	12.71	0.06	6.54
	3	0.46	0.28	1.24	0.93	0.63	1.97	0.22	4.23	0.09	8.28	0.05	9.76
71	1	0.35	0.10	2.14	0.42	2.96	1.48	0.48	2.07	0.13	2.25	0.06	2.86
	2	0.25	0.14	1.86	0.78	2.71	1.56	0.44	1.66	0.11	3.84	0.16	2.43
	3	0.28	0.09	1.86	0.25	2.88	0.33	0.74	0.52	0.18	1.84	0.28	2.11
72	1	0.18	0.07	0.85	0.35	1.56	1.03	0.36	0.46	0.13	1.02	0.09	3.25
	2	0.08	0.06	0.60	0.37	1.33	1.03	1.05	0.75	0.46	1.22	0.39	2.14
	3	0.07	0.06	0.27	0.25	0.78	0.87	0.65	0.71	0.19	1.30	0.13	1.09
75	1	0.57	0.58	1.67	1.22	0.76	2.65	0.26	5.13	0.01	9.52	0.01	13.27
	2	0.70	0.37	3.23	0.70	1.17	1.42	0.42	4.66	0.13	12.83	0.08	8.53
	3	0.47	0.27	2.10	0.59	1.04	1.55	0.29	4.41	0.14	8.79	0.05	11.70
76	1	0.56	0.40	2.12	1.29	0.86	2.25	0.20	3.72	0.01	6.84	0.01	8.00
	2	0.30	0.27	1.53	0.57	0.96	1.39	0.36	3.36	0.20	9.31	0.01	8.74
	3	0.56	0.38	1.99	0.60	1.18	1.37	0.50	3.28	0.15	9.43	0.08	11.07

Appendix Table 1b. Continued

Treatment Number	Replication	Harvest 1 G[1]	Harvest 1 C	Harvest 2 G	Harvest 2 C	Harvest 3 G	Harvest 3 C	Harvest 4 G	Harvest 4 C	Harvest 5 G	Harvest 5 C	Harvest 6 G	Harvest 6 C
		g/pot											
79	1	0.23	0.10	1.59	0.30	4.34	1.05	2.71	1.67	0.48	1.71	0.02	4.30
	2	0.39	0.11	2.53	0.31	4.62	0.41	2.69	0.32	0.47	1.82	0.31	2.61
	3	0.42	0.16	2.51	0.53	4.30	0.94	1.60	1.42	0.23	2.50	0.24	2.95
80	1	0.12	0.07	0.96	0.31	2.40	0.76	2.45	1.28	0.47	1.67	0.16	2.61
	2	0.13	0.06	1.25	0.37	2.33	1.08	1.18	0.60	0.39	1.17	0.45	2.78
	3	0.38	0.08	1.81	0.22	3.29	0.75	1.87	0.69	0.67	1.51	0.41	3.62
83	1	0.88	0.30	3.09	0.76	2.89	1.57	0.42	3.98	0.06	10.86	0.04	14.68
	2	1.03	0.53	3.91	1.51	1.37	2.24	0.36	4.14	0.20	6.04	0.21	6.56
	3	0.72	0.41	3.52	1.00	1.50	1.89	0.26	4.68	0.08	13.22	0.03	7.42
84	1	0.71	0.27	2.39	0.96	1.50	1.76	0.42	4.01	0.08	8.34	0.15	9.96
	2	0.61	0.39	3.49	1.00	1.04	1.45	0.51	3.11	0.10	11.17	0.12	10.17
	3	0.81	0.29	3.49	0.94	1.38	1.56	0.30	3.80	0.15	11.85	0.14	7.18
87	1	0.21	0.05	1.47	0.42	2.33	0.84	0.29	0.33	0.22	0.53	0.27	0.87
	2	0.16	0.12	1.13	0.55	2.07	1.33	0.24	0.41	0.06	1.00	0.19	1.19
	3	0.18	0.09	1.10	0.61	2.07	1.24	0.34	0.89	0.11	0.97	0.06	1.95
88	1	0.10	0.05	0.83	0.28	1.53	0.63	0.63	0.84	0.15	0.78	0.01	1.97
	2	0.20	0.09	1.07	0.32	1.72	1.04	0.27	0.45	0.01	0.98	0.11	1.53
	3	0.18	0.07	1.00	0.23	1.91	0.92	0.39	0.34	0.11	0.42	0.25	0.74
91	1	0.43	0.13	2.58	0.55	3.06	1.09	0.47	0.95	0.14	1.48	0.01	3.63
	2	0.52	0.13	3.08	0.69	3.03	0.97	0.49	1.57	0.18	1.83	0.21	2.48
	3	0.40	0.16	1.94	0.63	2.98	1.08	0.68	0.76	0.14	1.58	0.06	2.56
92	1	0.30	0.05	1.20	0.31	2.24	0.57	0.97	0.95	0.36	0.35	0.51	0.92
	2	0.43	0.08	1.75	0.34	2.43	0.82	0.27	0.57	0.23	2.84	0.01	2.78
	3	0.42	0.10	1.64	0.34	2.67	0.75	0.61	0.88	0.17	1.90	0.11	4.32

Appendix Table 1b. Continued

Treatment Number	Replication	Harvest 1 G[1]	Harvest 1 C	Harvest 2 G	Harvest 2 C	Harvest 3 G	Harvest 3 C	Harvest 4 G	Harvest 4 C	Harvest 5 G	Harvest 5 C	Harvest 6 G	Harvest 6 C
		g/pot											
95	1	0.44	0.20	3.05	1.01	4.07	1.63	0.72	2.60	0.04	1.95	0.03	3.82
	2	0.40	0.11	2.83	0.65	4.49	1.13	1.76	1.93	0.20	2.70	0.15	3.10
	3	0.59	0.20	3.71	0.97	3.54	1.50	0.49	1.45	0.08	2.16	0.35	1.40
96	1	0.44	0.05	2.47	0.52	3.41	1.29	0.50	1.92	0.27	1.34	0.49	1.85
	2	0.43	0.08	3.58	0.41	3.07	0.43	0.33	1.95	0.20	2.44	0.41	3.89
	3	0.42	0.08	2.21	0.26	3.13	0.53	0.76	1.15	0.26	3.85	0.12	2.45
99	1	0.66	0.39	1.14	0.81	0.52	1.62	0.16	3.65	0.05	6.43	0.02	10.78
	2	0.50	0.31	1.18	0.76	0.59	1.74	0.21	3.79	0.09	8.91	0.11	10.01
	3	0.60	0.26	1.28	0.65	0.95	1.51	0.56	3.15	0.27	7.61	0.12	8.00
100	1	0.69	0.31	1.13	0.65	0.66	1.44	0.26	3.17	0.13	4.87	0.34	10.64
	2	0.40	0.29	1.20	0.46	0.93	0.75	----	----	0.22	6.98	0.31	4.32
	3	0.49	0.32	1.58	1.00	1.04	2.20	0.38	3.41	0.20	6.79	0.15	7.20
103	1	0.04	0.06	0.21	0.29	0.64	0.75	0.23	0.18	0.10	0.14	0.40	0.03
	2	0.13	0.08	0.62	0.32	0.91	0.80	0.17	0.10	0.20	0.01	0.34	0.06
	3	0.11	0.08	0.47	0.26	1.15	0.76	0.61	0.16	0.17	0.01	0.44	0.05
104	1	0.08	0.06	0.27	0.26	0.51	0.66	0.36	0.45	0.14	0.04	0.44	0.01
	2	0.14	0.07	0.55	0.31	1.14	0.80	0.31	0.10	0.41	0.07	0.52	0.05
	3	0.13	0.10	0.72	0.32	1.81	0.93	0.61	0.34	0.33	0.14	0.29	0.30
107	1	0.91	0.48	1.93	0.93	0.79	2.12	0.31	4.33	0.05	7.30	0.01	9.45
	2	0.73	0.44	2.02	0.98	1.09	1.36	0.51	3.52	0.16	11.77	0.02	6.68
	3	0.89	0.39	2.16	1.14	0.92	1.55	0.24	4.00	0.13	9.67	0.06	6.58
108	1	0.60	0.46	2.15	0.81	1.06	1.75	0.22	5.41	0.01	9.97	0.02	9.49
	2	0.52	0.33	2.12	0.75	1.25	0.85	0.34	2.82	0.20	7.04	0.34	8.17
	3	0.56	0.39	2.22	0.74	0.91	1.64	0.32	3.39	0.16	8.52	0.22	6.07

Appendix Table 1b. Continued

Treatment Number	Replication	Harvest 1		2		3		4		5		6	
		G[1]	C	G	C	G	C	C	C	G	C	G	C
		g/pot											
111	1	0.43	0.42	2.26	1.11	1.38	1.41	0.33	1.77	0.35	1.09	0.59	1.38
	2	0.48	0.29	2.30	1.16	1.89	1.66	0.58	1.32	0.45	1.95	0.66	1.90
	3	0.54	0.23	2.15	0.82	2.31	1.25	0.46	1.16	0.16	2.91	0.04	4.54
112	1	0.38	0.18	1.89	0.90	1.95	1.10	0.56	1.57	0.47	0.98	0.85	1.34
	2	0.43	0.15	2.98	0.80	2.15	1.21	0.39	1.86	0.14	2.92	0.10	4.83
	3	0.30	0.30	1.42	1.19	1.25	1.73	0.14	1.27	0.26	1.55	0.43	1.82
115	1	0.77	0.45	3.44	0.99	1.40	2.16	0.34	3.97	0.01	7.95	0.05	8.73
	2	0.95	0.32	3.66	0.70	1.29	1.28	0.25	3.53	0.07	9.32	0.06	8.78
	3	0.52	0.33	2.05	0.71	2.07	1.31	0.49	2.80	0.06	7.81	0.01	10.36
116	1	0.84	0.46	2.86	1.03	1.31	1.76	0.26	3.83	0.01	7.35	0.01	8.86
	2	0.70	0.37	2.93	1.32	1.78	1.43	0.47	3.23	0.33	6.78	0.19	6.46
	3	0.77	0.27	3.01	0.90	2.03	1.51	0.19	3.27	0.06	10.15	0.01	3.68
119	1	0.52	0.26	1.80	1.03	2.94	1.49	0.69	1.35	0.17	1.28	0.07	3.22
	2	0.48	0.28	2.21	1.15	2.78	1.47	0.55	1.35	0.18	2.04	0.43	2.42
	3	0.52	0.27	2.83	0.73	3.30	1.52	1.30	1.30	0.64	0.94	0.90	1.24
120	1	0.43	0.29	1.67	0.93	2.53	2.11	0.61	1.89	0.26	1.60	0.32	2.35
	2	0.47	0.15	2.32	0.75	3.06	1.70	0.94	1.45	0.27	1.29	0.49	1.29
	3	0.47	0.28	2.17	1.04	3.42	1.53	1.10	1.44	0.32	1.82	0.35	2.08
123	1	0.62	0.31	3.51	0.78	4.25	0.76	0.82	2.32	0.01	6.04	0.00	8.29
	2	0.92	0.29	4.21	0.52	6.35	0.74	0.99	1.16	0.19	6.81	0.06	3.41
	3	0.71	0.27	3.38	0.72	3.49	1.27	0.63	2.20	0.06	6.86	0.03	6.67
124	1	0.47	0.26	1.92	1.03	2.99	1.96	0.35	3.06	0.01	6.57	0.01	8.39
	2	0.58	0.42	2.88	1.86	2.40	1.90	0.36	3.26	0.01	6.26	0.05	9.16
	3	0.57	0.24	2.73	0.48	4.31	1.17	1.09	1.32	0.04	0.55	0.01	10.30

Appendix Table 1b. Continued

Treatment Number	Replication	Harvest 1 G[1]	C	2 G	C	3 G	C	4 G	C	5 G	C	6 G	C
		g/pot											
127	1	0.42	0.24	2.39	0.98	4.10	1.67	1.71	1.45	0.45	0.95	0.66	1.08
	2	0.46	0.25	2.06	0.86	3.52	1.48	1.65	0.71	0.29	1.40	0.20	4.14
	3	0.40	0.19	1.55	0.68	3.23	1.18	3.10	1.12	0.88	1.08	0.67	1.28
128	1	0.52	0.32	2.31	0.98	3.74	1.53	1.09	0.57	0.60	0.65	0.49	0.79
	2	0.49	0.32	2.71	0.84	4.36	1.22	1.78	1.91	0.43	1.94	0.27	3.08
	3	0.36	0.20	1.69	0.82	2.93	1.55	2.87	1.21	0.67	1.13	0.20	2.90

Appendix Table 2. Nitrogen and phosphorus concentration in orchardgrass. Greenhouse experiment I.

Treatment Number[2]	Replication	Harvest 1	2	3	4	Harvest 1	2	3	4
		%N				%P			
1	1		2.25		1.97	0.25	0.19		0.68
	2		1.46		1.16	0.24	0.16		0.68
	3		1.59		1.72	0.25	0.18		0.69
2	1		3.03		1.73				
	2		1.19		1.22				
	3		1.62		1.32				
5	1		3.88		0.99	0.21	0.18		0.11
	2		3.26		1.04	0.17	0.14		0.12
	3		3.47		1.03	0.19	0.16		0.11
6	1		2.77		1.50				
	2		3.55		1.02				
	3		3.45		1.16				
9	1	3.96	2.82	1.41	1.80	0.27	0.21	0.32	0.80
	2	3.96	2.10	1.29	1.72	0.28	0.21	0.40	0.67
	3	4.05	2.22	1.36	(1.90)[1]	0.30	0.21	0.40	0.77
10	1	4.14	2.41	1.38	1.81	0.24	0.17	0.34	0.67
	2	3.90	1.53	1.52	1.63	0.23	0.21	0.47	0.65
	3	3.87	1.75	1.00	(1.86)[1]	0.24	0.16	0.37	0.57
13	1	4.36	3.70	2.14	1.13	0.25	0.19	0.11	0.17
	2	4.43	3.53	1.51	1.24	0.26	0.18	0.11	0.25
	3	4.36	3.06	2.86	1.76	0.24	0.21	0.18	0.14
14	1	5.19	3.58	2.41	1.08	0.19	0.13	0.09	0.13
	2	4.76	3.89	2.18	1.00	0.22	0.17	0.11	0.22
	3	4.01	3.31	1.62	(1.18)[1]	0.15	0.14	0.09	----

1 Estimated (Steel and Torrie 1960).

2 Table 8, page 46.

Appendix Table 2. Continued.

Treatment Number	Replication	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 1	Harvest 2	Harvest 3	Harvest 4
		%N				%P			
17	1		2.95		1.73	0.31	0.19		0.84
	2		2.57		1.34	0.27	0.21		0.86
	3		2.38		2.16	0.28	0.21		0.95
18	1		2.29		1.62				
	2		2.03		1.32				
	3		2.06		1.27				
21	1		3.62		1.21	0.25	0.18		0.16
	2		3.30		0.98	0.22	0.21		0.17
	3		3.38		1.33	0.24	0.21		0.18
22	1		3.55		1.34				
	2		3.60		1.08				
	3		3.93		1.33				
41	1	4.48	3.33	1.26	1.29	0.26	0.17	0.16	0.18
	2	4.60	3.46	2.07	1.18	0.25	0.20	0.11	0.14
	3	4.03	3.45	1.86	1.56	0.30	0.20	0.11	0.17
42	1	4.40	3.66	1.39	1.60	0.18	0.16	0.15	0.35
	2	4.37	3.56	1.20	1.02	0.18	0.19	0.09	0.25
	3	----	3.57	1.87	1.76	0.13	0.20	0.09	0.40
61	1		3.69		1.17	0.25	0.16		0.18
	2		3.71		1.12	0.21	0.17		0.14
	3		3.41		1.20	0.17	0.17		0.15
62	1		3.67		1.22				
	2		3.41		1.17				
	3		3.87		1.34				

Appendix Table 2. Continued

Treatment Number	Replication	Harvest 1	2	3	4	Harvest 1	2	3	4
		--------%N--------				--------%P--------			
65	1		1.31		1.58	0.23	0.13		0.51
	2		2.00		2.03	0.22	0.21		0.75
	3		1.59		1.87	0.22	0.16		0.64
66	1		1.54		1.16				
	2		1.36		1.67				
	3		2.54		(1.51)[1]				
69	1	4.73	3.61	1.64	1.26	0.24	0.21	0.13	0.27
	2	4.27	2.94	1.10	1,56	0.22	0.21	0.12	0.85
	3	4.48	3.49	1.75	1.17	0.21	0.20	0.10	0.62
70	1	----	3.77	2.30	1.76	0.19	0.14	0.10	0.15
	2	4.82	3.27	2.19	0.98	0.25	0.14	0.10	0.11
	3	4.95	3.32	2.36	1.26	0.27	0.15	0.10	0.19
73	1	3.91	3.16	1.19	1.68	0.31	0.21	0.28	0.83
	2	4.11	2.35	1.28	1.26	0.30	0.19	0.31	0.39
	3	3.87	2.73	1.22	2.27	0.23	0.20	0.27	0.71
74	1	4.19	2.01	1.42	1.11	0.22	0.14	0.35	0.67
	2	4.43	2.32	1.56	1.65	0.28	0.17	0.32	0.57
	3	4.01	1.94	1.23	1.82	0.22	0.16	0.32	0.60
77	1		3.72		1.63	0.21	0.19		0.21
	2		3.60		1.31	0.24	0.21		0.28
	3		3.47		1.67	0.22	0.22		0.15
78	1		4.02		1.83				
	2		3.42		1.14				
	3		3.31		1,26				

Appendix Table 2. Continued

Treatment Number	Replication	Harvest (%N) 1	2	3	4	Harvest (%P) 1	2	3	4
81	1		3.64		1.71	0.25	0.20		0.77
	2		2.81		1.94	0.28	0.21		0.67
	3		3.27		1.37	0.27	0.23		0.48
82	1		3.17		1.53				
	2		2.23		1.63				
	3		3.10		1.10				
89	1	4.27	3.28	1.40	1.17	0.26	0.16	0.13	0.19
	2	4.22	3.28	1.31	1.47	0.24	0.18	0.11	0.25
	3	4.13	4.52	1.95	1.23	0.26	0.22	0.14	0.21
90	1	4.56	3.24	1.35	1.60	0.24	0.14	0.10	0.24
	2	4.00	3.46	1.63	1.56	0.18	0.17	0.08	0.26
	3	4.38	3.24	1.49	1.68	0.19	0.15	0.09	0.31
97	1					0.25	0.17	0.33	0.54
	2					0.30	0.20	0.26	0.49
	3					0.21	0.16	0.26	0.46
98	1	3.70	1.78	1.47	1.22				
	2	3.80	1.57	1.51	1.51				
	3	3.98	2.00	1.47	1.93				
101	1					0.18	0.11	0.09	0.11
	2					0.18	0.14	0.09	0.09
	3					0.16	0.13	0.10	0.10
102	1	4.87	3.88	2.83	1.59				
	2	4.60	3.77	2.59	1.11				
	3	5.03	3.81	2.68	1.18				

Appendix Table 2. Continued

Treatment Number	Replication	Harvest				Harvest			
		1	2	3	4	1	2	3	4
		%N				%P			
105	1					0.27	0.16		0.73
	2					0.26	0.20		0.69
	3					0.21	0.21		0.65
106	1		1.87		1.37				
	2		2.26		1.68				
	3		2.40		----				
109	1					0.21	0.15		0.29
	2					0.23	0.14		0.46
	3					0.21	0.18		0.20
110	1		3.43		1.70				
	2		3.00		1.61				
	3		3.61		1.58				
113	1					0.28	0.18	0.25	0.65
	2					0.28	0.21	0.27	0.72
	3					0.25	0.19	0.21	0.58
114	1	3.73	2.93	1.28	1.60				
	2	4.17	2.44	1.13	1.64				
	3	4.11	3.06	1.19	1.76				
117	1					0.25	0.14	0.11	0.17
	2					0.24	0.15	0.10	0.21
	3					0.22	0.20	0.10	0.11
118	1	4.39	3.43	1.99	1.31				
	2	4.39	3.64	1.54	1.26				
	3	4.31	3.55	1.92	(1.57)[1]				

Appendix Table 2. Continued

Treatment Number	Replication	Harvest 1	2	3	4	Harvest 1	2	3	4
		--------%N--------				--------%P--------			
121	1					0.27	0.15		0.49
	2					0.28	0.19		0.33
	3					0.23	0.16		0.30
122	1		3.74		1.23				
	2		3.74		1.40				
	3		3.34		1.71				
125	1					0.22	0.15		0.12
	2					0.29	0.18		0.17
	3					0.24	0.21		0.11
126	1		3.88		1.58				
	2		4.02		1.26				
	3		3.71		1.64				

Appendix Table 3. Phosphorus concentration in white clover. Greenhouse experiment I.

Treatment Number[2]	Replication	Harvest 1	2	3	4	5	6
		%P					
3	1		0.27		0.16		0.09
	2		0.26		0.21		0.15
	3		0.32		0.17		0.12
4	1		0.29		0.19		0.09
	2		0.29		0.21		0.15
	3		0.29		0.20		0.14
7	1		0.28		0.13		0.11
	2		0.28		0.11		0.12
	3		0.24		0.10		0.11
8	1		0.27		0.13		0.09
	2		0.20		0.14		0.13
	3		0.23		0.14		0.10
11	1	0.35	0.32	0.24	0.19	0.16	0.14
	2	0.32	0.31	0.27	0.18	0.12	0.13
	3	0.32	0.33	0.25	0.22	0.11	0.16
12	1	0.28	0.32	0.28	0.19	0.17	0.13
	2	0.30	0.32	0.23	0.19	0.16	0.11
	3	0.31	0.38	0.26	0.19	0.11	(0.13)[1]
15	1	0.28	0.26	0.18	0.14	0.18	0.10
	2	0.27	0.25	0.18	0.16	0.14	0.12
	3	0.27	0.27	0.18	0.14	0.11	0.07
16	1	0.31	0.28	0.14	0.13	0.16	0.09
	2	0.25	0.26	0.12	0.11	0.16	0.10
	3	0.23	0.24	0.11	0.11	0.10	0.13

[1] Estimated (Steel and Torrie 1960).

[2] Table 8, page 46.

Appendix Table 3. (Continued)

Treatment Number	Replication	Harvest 1	2	3	4	5	6
		---------------------------	%P	---------------------------			
19	1		0.34		0.21		0.11
	2		0.36		0.19		0.16
	3		0.37		0.23		0.13
20	1		0.34		0.22		0.11
	2		0.36		0.27		0.14
	3		0.35		0.22		0.11
23	1		0.30		0.16		0.11
	2		0.34		0.16		0.16
	3		0.30		0.18		0.21
24	1		0.27		0.18		0.16
	2		0.33		0.19		0.13
	3		0.33		0.22		(0.16)[1]
43	1	0.28	0.32	0.15	0.12	0.19	0.09
	2	0.28	0.30	0.17	0.17	0.19	0.16
	3	0.27	0.30	0.20	0.18	0.15	0.14
44	1	0.15	0.28	0.18	0.14	0.12	0.13
	2	----	0.30	0.17	0.17	0.12	0.14
	3	0.23	0.27	0.11	0.16	0.11	0.16
63	1		0.23		0.13		0.06
	2		0.27		0.12		0.13
	3		0.25		0.15		0.09
64	1		0.19		0.13		0.08
	2		0.24		0.15		0.13
	3		0.24		0.20		0.17

Appendix Table 3. (Continued)

Treatment Number	Replication	Harvest 1	2	3	4	5	6
		--------------------	--------------------	--------------------	%P	--------------------	--------------------
67	1		0.26		0.24		0.09
	2		0.30		0.18		0.10
	3		0.33		0.17		0.10
68	1		0.26		0.14		0.13
	2		0.26		0.13		0.12
	3		0.30		0.18		0.12
71	1	0.22	0.29	0.18	0.14	0.15	0.12
	2	0.33	0.29	0.21	0.21	0.15	0.20
	3	0.23	0.30	0.19	0.19	0.14	0.16
72	1	0.25	0.21	0.13	0.15	0.16	0.10
	2	0.22	0.35	0.14	0.12	0.16	0.12
	3	0.24	0.28	0.16	0.14	0.11	0.11
75	1	0.31	0.35	0.22	0.20	0.12	0.09
	2	0.32	0.22	0.26	0.19	0.13	0.09
	3	0.31	0.28	0.28	0.21	0.13	0.14
76	1	0.26	0.28	0.24	0.15	0.17	0.09
	2	0.33	0.31	0.28	0.22	0.18	0.12
	3	0.26	0.36	0.27	0.19	0.13	0.10
79	1		0.26		0.17		0.13
	2		0.29		0.20		0.15
	3		0.32		0.21		0.14
80	1		0.22		0.14		0.10
	2		0.22		0.10		0.14
	3		0.33		0.17		0.14

Appendix Table 3. (Continued)

Treatment Number	Replication	Harvest 1	2	3	4	5	6
		%P					
83	1		0.33		0.23		0.20
	2		0.34		0.20		0.19
	3		0.23		0.22		0.12
84	1		0.28		0.20		0.10
	2		0.33		0.22		0.12
	3		0.35		0.21		0.11
91	1	0.26	0.29	0.20	0.18	0.18	0.10
	2	0.30	0.29	0.17	0.13	0.17	0.12
	3	0.27	0.34	0.20	0.16	0.13	0.14
92	1	0.18	0.20	0.18	0.12	0.11	0.13
	2	0.26	0.28	0.14	0.20	0.12	0.14
	3	0.24	0.31	0.19	0.18	0.13	0.13
99	1	0.27	0.26	0.27	0.15	0.16	0.17
	2	0.28	0.31	0.26	0.18	0.13	0.11
	3	0.28	0.26	0.27	0.17	0.10	0.19
103	1	0.15	0.20	0.11	0.15	0.20	0.06
	2	0.29	0.25	0.09	0.13	0.22	0.10
	3	0.21	0.27	0.14	0.09	0.12	(0.09)[1]
107	1		0.31		0.22		0.10
	2		0.34		0.22		0.12
	3		0.30		0.18		0.10

Appendix Table 3. (Continued)

Treatment Number	Replication	Harvest 1	2	3	4	5	6
		%P					
111	1		0.25		0.13		0.12
	2		0.27		0.19		0.15
	3		0.29		0.16		0.09
115	1	0.31	0.27	0.22	0.17	0.13	0.10
	2	0.34	0.32	0.26	0.20	0.13	0.10
	3	0.32	0.35	0.27	0.20	0.14	0.11
119	1	0,26	0.30	0.15	0.15	0.14	0.08
	2	0.29	0.33	0.17	0.12	0.14	0.13
	3	0.27	0.31	0.15	0.11	0.11	0.12
123	1		0.27		0.16		0.08
	2		0.32		0.18		0.18
	3		0.34		0.19		0.11
127	1		0.27		0.13		0.09
	2		0.31		0.13		0.13
	3		0.34		0.14		0.16

[1] Estimated (Steel and Torrie 1960).

Appendix Table 4. Soil chemical analysis of Knappa and Nehalem silt loams sampled 28 weeks after waste application. Greenhouse experiment I.

Treatment Number[1]	Replication	pH	SMP	P	K	B	Ca	Mg
				---------ppm---------			---meq/100g---	
1	1	5.3	6.3	19	140	0.57	7.5	3.1
	2	5.5	6.3	18	146	0.50	7.7	3.2
	3	5.3	6.3	17	146	0.52	8.6	3.2
2	1	5.4	6.5	19	156	0.53	7.5	3.1
	2	5.3	6.3	21	164	0.57	8.6	3.2
	3	5.5	6.3	19	164	0.45	8.3	3.1
5	1	4.9	4.8	12	112	0.72	1.9	0.82
	2	5.0	5.0	13	96	0.89	1.9	0.82
	3	5.1	4.9	12	96	0.73	1.9	0.82
6	1	5.0	4.9	13	136	0.84	1.8	0.76
	2	5.0	4.9	13	112	0.83	1.6	0.82
	3	5.0	4.9	15	112	0.89	1.8	0.82
9	1	5.4	6.3	17	128	0.55	8.9	2.7
	2	5.6	6.3	21	116	0.49	9.1	3.4
	3	5.5	6.3	21	128	0.51	9.5	3.4
10	1	5.5	6.3	21	156	0.49	9.1	3.5
	2	5.4	6.3	21	140	0.53	8.6	3.3
	3	5.4	6.3	20	116	0.59	8.6	3.2
13	1	4.9	4.9	11	88	0.71	2.3	0.82
	2	4.9	4.9	13	72	0.80	2.3	0.82
	3	4.8	5.0	14	84	0.72	2.3	0.89
14	1	4.8	5.0	13	100	0.84	1.9	0.76
	2	4.7	4.9	13	124	0.80	1.8	0.76
	3	4.8	5.1	12	88	0.71	2.5	0.89

[1] Table 8, page 46.

Appendix Table 4. (Continued)

Treatment Number	Replication	pH	SMP	P	K	B	Ca	Mg
				---------ppm---------			---meq/100g---	
17	1	5.6	6.4	23	100	0.61	9.7	3.6
	2	5.5	6.4	25	88	0.52	9.1	3.4
	3	5.5	6.3	27	88	0.64	9.5	3.6
18	1	5.5	6.3	20	112	0.54	8.6	3.3
	2	5.5	6.3	18	140	0.44	9.0	3.4
	3	5.7	6.3	21	124	0.50	9.7	3.3
21	1	4.9	5.0	15	76	0.98	3.0	0.89
	2	4.7	4.9	14	76	0.70	3.0	0.92
	3	4.9	5.1	23	72	0.76	2.7	0.82
22	1	4.8	5.0	14	84	0.73	4.3	0.99
	2	4.9	4.9	12	96	0.69	2.4	0.89
	3	4.8	5.0	12	84	0.79	2.5	0.89
61	1	5.0	5.1	10	116	0.69	1.9	0.76
	2	5.0	4.9	8	140	0.64	1.9	0.82
	3	5.0	4.9	9	128	0.71	1.9	0.82
62	1	5.1	5.0	10	128	0.60	1.8	0.69
	2	5.1	4.9	9	124	0.59	1.8	0.69
	3	5.1	4.9	10	128	0.63	1.6	0.69
65	1	5.5	6.4	16	170	0.35	9.0	3.3
	2	5.4	6.3	19	152	0.53	8.4	3.5
	3	5.4	6.4	19	140	0.49	8.4	3.1
66	1	5.5	6.3	18	164	0.45	7.9	3.4
	2	5.5	6.4	18	164	0.56	8.1	3.4
	3	5.4	6.6	16	180	0.68	8.1	3.4

Appendix Table 4. (Continued)

Treatment Number	Replication	pH	SMP	P	K	B	Ca	Mg
				---------ppm	----------		---meq/100g---	
69	1	5.1	4.8	9	100	0.67	2.5	0.76
	2	5.1	4.9	10	96	0.65	2.4	0.76
	3	5.1	4.9	12	100	0.61	2.3	0.69
70	1	5.3	5.0	10	128	0.70	2.3	0.76
	2	5.2	4.8	8	124	0.58	2.4	0.82
	3	5.1	4.9	10	112	0.66	2.3	0.69
73	1	5.5	6.6	18	152	0.68	9.1	3.6
	2	5.7	6.4	21	136	0.38	9.7	3.2
	3	5.4	6.7	20	152	0.64	8.6	3.4
74	1	5.4	6.6	15	180	0.64	7.5	3.3
	2	5.5	6.6	17	180	0.48	8.1	3.5
	3	5.3	6.3	25	156	0.48	9.3	3.3
77	1	5.1	4.9	9	76	0.68	3.5	0.82
	2	5.1	5.0	9	72	0.70	3.7	0.82
	3	5.1	5.0	10	76	0.73	3.8	0.89
78	1	5.2	5.0	10	116	0.73	3.0	0.76
	2	5.1	5.0	10	96	0.58	2.7	0.69
	3	5.0	5.1	11	76	0.84	3.8	0.89
81	1	5.7	6.7	21	128	0.73	9.3	3.4
	2	5.5	6.5	20	146	0.73	10.3	3.8
	3	5.5	6.7	22	152	0.71	10.1	3.6
82	1	5.4	6.5	18	146	0.71	7.9	3.4
	2	5.5	6.4	17	164	0.62	7.9	3.4
	3	5.5	6.3	19	128	0.52	8.6	3.0

Appendix Table 4 (Continued)

Treatment Number	Replication	pH	SMP	P	K	B	Ca	Mg
				---------ppm---------			---meq/100---	
97	1	5.3	6.5	16	186	0.72	7.2	3.3
	2	5.6	6.6	18	180	0.68	7.2	3.3
	3	5.5	6.3	19	170	0.48	8.3	3.2
101	1	5.1	5.2	11	140	0.53	1.5	0.82
	2	5.0	5.1	11	140	0.69	1.3	0.76
	3	4.9	5.0	10	146	0.58	1.5	0.82
105	1	5.9	6.5	20	156	0.74	8.6	4.0
	2	5.9	6.5	22	174	0.67	8.3	3.8
	3	5.8	6.6	20	164	0.68	8.1	3.8
109	1	5.5	5.5	8	54	0.74	6.8	2.8
	2	5.5	5.5	7	64	0.74	7.1	3.0
	3	5.6	5.6	7	60	0.75	7.4	3.0
113	1	5.8	6.4	15	146	0.66	9.9	4.1
	2	5.8	6.5	14	156	0.61	8.6	3.8
	3	5.7	6.2	23	124	0.49	11.0	3.9
117	1	5.5	5.5	8	54	0.73	6.9	2.9
	2	5.4	5.6	8	48	0.79	7.7	3.2
	3	5.6	5.5	8	54	0.81	7.2	3.0
121	1	5.9	6.6	17	124	0.65	8.3	3.8
	2	5.8	6.5	17	100	0.69	8.1	3.7
	3	5.6	6.3	21	124	0.48	9.0	3.9
125	1	5.5	5.6	8	44	0.76	7.1	2.8
	2	5.5	5.5	7	54	0.71	7.7	3.1
	3	5.5	5.6	11	64	0.76	6.9	2.8

Appendix Table 5. Soil chemical analysis of Knappa and Nehalem silt loams sampled 42 weeks after waste application. Greenhouse experiment I.

Treatment Number [1]	Replication	pH	p	Treatment Number	Replication	pH	p
			ppm				ppm
3	1	5.3	14	19	1	5.2	15
	2	5.4	12		2	5.6	15
	3	5.5	11		3	5.6	15
4	1	5.5	11	20	1	5.5	13
	2	5.4	12		2	5.6	14
	3	5.3	12		3	5.5	16
7	1	5.0	7	23	1	5.0	10
	2	4.9	7		2	5.0	7
	3	5.0	7		3	5.1	8
8	1	5.0	13	24	1	5.0	11
	2	5.1	6		2	4.9	6
	3	5.0	6		3	5.2	7
11	1	5.3	13	63	1	4.9	13
	2	5.5	14		2	4.9	8
	3	5.5	14		3	5.1	6
12	1	5.5	13	64	1	5.0	8
	2	5.5	14		2	5.1	12
	3	5.4	16		3	5.0	8
15	1	5.0	7	67	1	5.3	11
	2	5.0	9		2	5.3	11
	3	4.9	11		3	5.4	12
16	1	4.9	6	68	1	5.6	13
	2	4.9	8		2	5.5	13
	3	5.0	6		3	5.2	11

[1] Table 8, page 46.

Appendix Table 5. (Continued)

Treatment Number	Replication	pH	p	Treatment Number	Replication	pH	p
			ppm				ppm
71	1	5.0	15	99	1	5.2	10
	2	4.9	8		2	5.3	11
	3	4.9	14		3	5.3	10
72	1	5.0	5	103	1	4.9	8
	2	5.0	5		2	4.9	8
	3	5.0	6		3	5.0	8
75	1	5.4	13	107	1	5.5	11
	2	5.5	12		2	5.5	12
	3	5.3	12		3	5.5	13
76	1	5.4	13	111	1	5.6	7
	2	5.5	13		2	5.6	7
	3	5.1	13		3	5.6	12
79	1	5.1	25	115	1	5.6	12
	2	5.0	17		2	5.5	12
	3	5.0	19		3	5.4	12
80	1	5.0	16	119	1	5.5	8
	2	5.1	14		2	5.6	10
	3	5.0	19		3	5.6	9
83	1	5.5	15	123	1	5.6	13
	2	5.4	13		2	5.5	16
	3	5.4	12		3	5.6	16
84	1	5.4	13	127	1	5.8	6
	2	5.4	11		2	5.5	8
	3	5.5	13		3	5.5	8

Appendix Table 6. Soil chemical analysis[1] of a coastal hill pasture after an estimated application of 50 to 150 tons of shrimp and crab wastes per acre.

Months after Application	pH	Ca	Mg	P	K	NO_3-N	SO_4-S	Soluble Salts
		---meq/100g---		----------ppm----------				mmhos/cm
Control	5.0	2.5	0.53	15	84	1.97	1.3	0.19
5 (September)[2]	6.1	12.4	1.30	91	136	338	24	5.0
10 (February)	6.9	15.1	1.10	149	48	18.7	3.6	0.51

[1] Sampled at 0 - 15 cm.

[2] Month of sampling .

Appendix Table 7. Orchardgrass yields. Greenhouse experiment II.

Nutrient Levels	Replication	Fertilizer: Shrimp, Harvest 1	Shrimp, Harvest 2	Shrimp, Harvest 3	Shrimp, Harvest 4	Inorganic, Harvest 1	Inorganic, Harvest 2	Inorganic, Harvest 3	Inorganic, Harvest 4
		g/pot							
N_1P_1	1	0.94	2.81	0.97	1.59	0.67	2.58	1.21	1.69
	2	0.90	2.60	1.42	1.42	0.80	2.66	1.58	1.70
	3	0.91	2.55	1.14	1.94	0.62	1.88	1.51	1.53
	4	0.82	2.37	1.04	1.37	0.83	1.81	1.37	1.38
N_1P_2	1	1.75	2.52	0.71	1.58	1.31	2.53	0.89	2.00
	2	1.35	2.68	0.96	1.76	1.33	2.64	0.97	1.44
	3	1.85	2.46	0.63	1.37	1.41	2.77	0.75	1.34
	4	1.23	2.88	0.79	1.70	1.59	2.79	0.71	1.73
N_2P_1	1	0.81	3.11	2.71	2.42	0.67	2.87	2.62	2.47
	2	0.92	2.85	2.64	2.38	0.60	2.72	2.53	2.18
	3	0.81	2.52	2.83	2.49	0.70	2.41	2.50	2.48
	4	0.95	2.88	2.74	2.52	0.52	2.14	2.57	2.46
N_2P_2	1	1.32	3.76	2.57	3.00	1.62	4.46	1.68	2.37
	2	1.48	3.60	2.69	2.39	0.89	2.86	3.16	2.14
	3	1.62	3.70	1.86	2.30	1.32	2.81	2.09	2.73
	4	1.41	3.92	2.07	2.37	1.21	2.89	2.60	2.92

Appendix Table 8. Nitrogen concentration in orchardgrass. Greenhouse experiment II.

Nutrient Levels	Replication	Fertilizer							
		Shrimp				Inorganic			
		Harvest				Harvest			
		1	2	3	4	1	2	3	4
		%N							
N_1P_1	1	3.39	2.05	1.86	0.89	3.56	2.70	2.01	0.98
	2	3.30	3.12	1.74	1.08	3.29	2.69	1.83	1.16
	3	3.51	2.06	1.80	0.89	3.42	3.40	2.01	1.34
	4	3.31	3.24	1.96	1.09	3.38	3.24	2.35	1.43
N_1P_2	1	3.01	2.04	1.94	1.04	3.42	2.22	1.85	0.92
	2	3.09	1.89	1.93	1.01	3.06	1.99	1.90	1.11
	3	3.11	1.81	2.02	0.94	3.10	2.08	2.00	0.94
	4	3.51	1.97	1.80	0.99	3.09	1.98	2.04	0.98
N_2P_1	1	3.63	3.85	2.27	1.22	3.70	3.40	2.65	1.54
	2	3.37	3.54	2.12	1.10	3.52	3.00	3.05	1.93
	3	3.36	3.94	2.33	1.31	3.56	3.58	2.87	1.72
	4	3.18	3.50	2.11	1.22	4.00	3.81	3.03	1.64
N_2P_2	1	3.47	3.50	1.83	0.99	3.65	2.75	1.89	0.92
	2	3.17	3.27	2.05	1.17	3.26	3.23	2.41	1.49
	3	3.19	3.16	1.67	0.92	3.47	3.55	2.06	1.12
	4	3.19	3.23	1.87	1.08	3.34	3.59	2.05	1.06

Appendix Table 9. Phosphorus concentration in orchardgrass. Greenhouse experiment II.

Nutrient Levels	Replication	Fertilizer: Shrimp, Harvest 1	Shrimp, Harvest 2	Shrimp, Harvest 3	Shrimp, Harvest 4	Inorganic, Harvest 1	Inorganic, Harvest 2	Inorganic, Harvest 3	Inorganic, Harvest 4
		%P							
N_1P_1	1	0.11	0.13	0.21	0.17	0.13	0.11	0.15	0.16
	2	0.10	0.14	0.21	0.20	0.13	0.12	0.14	0.15
	3	0.12	0.13	0.17	0.17	0.11	0.14	0.14	0.14
	4	0.11	0.13	0.22	0.20	0.11	0.12	0.14	0.18
N_1P_2	1	0.15	0.20	0.41	0.26	0.13	0.14	0.25	0.24
	2	0.12	0.17	0.33	0.19	0.12	0.13	0.32	0.23
	3	0.11	0.19	0.38	0.27	0.11	0.16	0.31	0.23
	4	0.13	0.15	0.35	0.23	0.11	0.14	0.40	0.25
N_2P_1	1	0.13	0.15	0.14	0.14	0.14	0.12	0.11	0.15
	2	0.11	0.13	0.14	0.12	0.13	0.10	0.12	0.19
	3	0.11	0.14	0.15	0.13	0.10	0.12	0.11	0.12
	4	0.10	0.14	0.14	0.14	0.10	0.13	0.10	0.12
N_2P_2	1	0.13	0.17	0.15	0.16	0.15	0.12	0.19	0.17
	2	0.11	0.14	0.24	0.18	0.12	0.14	0.12	0.18
	3	0.11	0.16	0.16	0.18	0.10	0.14	0.16	0.16
	4	0.10	0.14	0.14	0.18	0.12	0.13	0.12	0.14

Appendix Table 10. Forage yields. Field experiment.

Fertilizer	Application Rate	Replication	Harvest 1	2	3	4	5
	(Kg/ha)		----------g/plot (dry matter)----------				
Control	0	1	251	346	147	141	33
		2	177	311	137	172	67
		3	267	605	235	235	145
		4	175	397	206	110	78
Shrimp	6,726	1	363	708	260	231	79
		2	289	659	219	216	91
		3	318	840	308	293	193
		4	338	626	227	154	102
	17,936	1	295	807	328	304	156
		2	275	743	296	333	195
		3	349	824	320	318	195
		4	186	937	345	260	146
	35,872	1	276	770	288	323	293
		2	216	574	310	283	283
		3	323	861	310	256	283
		4	277	755	356	310	312
Ammonium phosphate	224.2	1	291	513	158	132	58
		2	307	496	167	162	81
		3	289	667	229	220	139
		4	300	633	220	191	127
	448.4	1	377	576	206	146	80
		2	279	576	251	119	80
		3	315	889	341	238	126
		4	332	560	242	146	80

Appendix Table 11. Nitrogen concentration in the forage. Field experiment.

Fertilizer	Application Rate	Replication	Harvest 1	2	3	4	5
	(Kg/ha)		%N				
Control	0	1	2.91	2.32	2.76	2.88	3.10
		2	3.27	2.81	2.80	3.05	3.10
		3	3.99	3.39	2.33	2.25	3.26
		4	3.09	3.18	2.83	3.19	3.17
Shrimp	6,726	1	4.62	3.43	3.45	3.31	2.98
		2	4.18	3.22	3.17	3.30	2.99
		3	4.89	4.24	3.76	3.10	3.22
		4	4.15	3.89	3.00	3.49	3.14
	17,936	1	4.32	3.83	4.14	4.28	3.98
		2	4.86	3.65	3.77	4.07	3.88
		3	4.47	4.46	3.62	3.80	3.07
		4	4.76	3.65	4.29	4.75	3.96
	35,872	1	5.08	3.93	4.57	4.20	4.11
		2	4.85	3.66	4.16	4.39	3.96
		3	4.68	3.53	3.63	3.72	4.30
		4	5.03	4.09	4.29	5.07	4.12
Ammonium phosphate	224.2	1	3.47	2.36	2.68	2.97	2.92
		2	3.72	2.78	2.72	3.17	3.03
		3	4.79	3.80	3.18	3.62	4.16
		4	4.22	3.55	3.11	3.80	3.40
	448.4	1	3.88	3.21	2.99	3.20	3.13
		2	4.28	2.87	2.76	3.02	3.06
		3	4.09	3.37	3.02	3.37	3.08
		4	4.02	3.70	2.70	3.39	2.97

Appendix Table 12. Phosphorus concentration in the forage. Field experiment.

Fertilizer	Application Rate	Replication	Harvest 1	2	3	4	5
	(Kg/ha)		---------------------------	%P	---------------------------		
Control	0	1	0.18	0.28	0.43	0.52	0.58
		2	0.19	0.19	0.41	0.39	0.53
		3	0.23	0.25	0.37	0.41	0.46
		4	0.21	0.22	0.42	0.40	0.47
Shrimp	6,726	1	0.22	0.20	0.37	0.40	0.50
		2	0.20	0.20	0.34	0.48	0.46
		3	0.24	0.22	0.35	0.31	0.41
		4	0.18	0.22	0.36	0.39	0.42
	17,936	1	0.19	0.21	0.36	0.29	0.34
		2	0.20	0.22	0.32	0.27	0.33
		3	0.22	0.22	0.35	0.32	0.34
		4	0.22	0.22	0.31	0.29	0.30
	35,872	1	0.21	0.22	0.36	0.32	0.33
		2	0.23	0.20	0.33	0.28	0.30
		3	0.19	0.28	0.43	0.28	0.30
		4	0.22	0.23	0.34	0.30	0.31
Ammonium phosphate	224.2	1	0.18	0.24	0.44	0.53	0.61
		2	0.20	0.24	0.40	0.44	0.52
		3	0.22	0.22	0.36	0.34	0.62
		4	0.22	0.22	0.36	0.36	0.49
	448.4	1	0.19	0.21	0.34	0.38	0.47
		2	0.19	0.21	0.37	0.35	0.43
		3	0.20	0.19	0.32	0.35	0.41
		4	0.20	0.27	0.32	0.37	0.47