Coastal British Columbia (BC) is a land-limited agricultural region with very high dairy animal densities on farms that provide much of the fresh milk used by a population of over 2.5 million people. The cost of land and the value of milk are such that farmers must maximize crop production, with fewer strict environmental regulations than typical in the EU. Hence most soils test high for P, yet silage maize crops which are critical to the industry receive manure and 25-35 kg P and 20 kg of N per ha as commercial starter fertilizer. We conducted several on-farm tests which supported this practice in terms of increasing concentration of dry matter and grain, and sometimes yield. Although there appears to be excessive nutrient inputs onto soils, high crop yield and quality help to reduce feed importation which in turn reduces surplus nutrients on farms. Our research over 20+ years has aimed to improve nutrient efficiency with little cost to farmers (few subsidies here) and the project reported here is part of a progression of studies on several fronts. The main objective of the studies was to determine the efficacy of P and N from precision-placed dairy slurry and high dry matter sludge (from dairy slurry settling). In both cases the goal was to replace all of the commercial P and some of the N currently used by farmers while maintaining crop production levels.

Materials and methods
All trials were conducted over 3 years at the Pacific Agri-food Research Centre (PARC), in southwestern BC, Canada. The region has a maritime climate with moderate temperatures year-round, a long growing season and heavy winter rains. Slurry manure was obtained from commercial dairy farms using sawdust bedding. The high dry matter sludge was generated by
allowing whole slurry to passively settle in a tank over winter and retrieved after decanting the supernatant which was used as a source of available N for grass. The whole slurry or sludge was injected (double disk openers) in furrows that were about 15 cm deep and spaced 75 cm apart to match the maize rows (Figure 1, left). About 5 days after manure application, maize was precision planted <10 cm from injection furrows using a commercial planter, with or without starter fertilizer (Figure 1, right).

**Sludge trial:** (8.4% DM and a 3.5:1 N:P ratio). In this study sludge was applied at 16 and 32 kg P ha⁻¹ (ca 23 and 46 t manure ha⁻¹) and ammonium nitrate fertilizer was applied to give various rates of N. Fertilizer was applied at the same rates of P with 20 kg N ha⁻¹ as starter at time of seeding and the remaining N was broadcast.

**Whole slurry trial:** (5.9% DM and 5.2:1 N:P ratio). Slurry was applied at increasing rates, with or without starter N and P; fertilizer plots also used starter N and P and matched slurry rates. A typical farm treatment was included in which both broadcast manure and starter fertilizer were applied.

**Results and Discussions**

Emergence was not impeded by close slurry or sludge injection and injected plots always looked robust and healthy (Figure 2.). Distance between seed and manure furrows varied from ~0 to 12 cm.

**Sludge trial:** In this trial application rates were based on P and adjusted for N rates with fertilizer. There was a linear increase of apparent P uptake (defined as P uptake of treatment - P uptake of control) by maize banded with fertilizer at 32 kg P ha⁻¹ due to increasing N rates (Figure 3). N application helped increase yield (numerical values on the graph in Figure 3) and increased yield was both the cause and result of increased P uptake. Apparent P uptake from sludge was about the same as from fertilizer at equivalent rates of P and N. At lower N rates sludge treatments received a greater proportion of N in the organic form so response to N tended to be a little less than with fertil-

![Figure 2. Emergence and growth of maize precision planted near injected slurry or sludge.](image)

![Figure 3. Effect of applied total N (organic and inorganic) on apparent P uptake (% of applied) and dry matter yields (numerical values on graph) of maize receiving commercial fertilizer with starter or injected sludge (mean of 2010-2012).](image)
Fertilization of maize with manure only

Whole Slurry trial: In this trial slurry application rates were compared at similar N and P rates. Maize yield responded to commercial N application (without P) while P with no N had no effect on yield (Figure 4). Adding commercial P fertilizer increased yield asymptotically. At equivalent rates of total N, response to precision-placed slurry (no commercial fertilizer) was consistently similar to commercial fertilizer. Note that at the intermediate manure level, P rates for fertilizer and manure were similar but at the high level manure P was higher. Current farm practice (broadcast slurry and starter N and P) can be consistently matched with precision-injected slurry and no starter. Starter fertilizer increased yield relative to the injected slurry but not at the high application rate. Maximum yield was possible with injected manure only, but the P rate was quite high (~50 kg ha⁻¹) and recovery rate was low (not shown here). Therefore some fertilizer N was needed for overall nutrient optimization.

Associated studies
In a separate trial there was a negative relationship between distance between manure and seed furrows, with best results when the distance was less than 10 cm (Bittman et al., 2012). Root colonization by mycorrhizal fungi was not affected by manure bands. Damage due to ammonium or salt effects have rarely been seen over 6 years under our conditions.

Conclusions
Whole dairy slurry and separated dairy sludge can replace starter N and P fertilizer with little or no loss in yield, but several research questions remain.

Co-benefits
Closed slot injection may save over 20 kg ha⁻¹ of ammonium-N, especially from the whole slurry, and reduces risk of runoff. Separation of manure sludge lowers application volume and hence reduces injection depth, power and costs. The supernatant is more effective as an N source for grass due to rapid soil infiltration and gives less P loading per kg N applied and per kg yield (shown in separate trials). This is described in more detail in our book ‘Cool Forages’ (Bittman et al., 2013).

Remaining challenges
We are seeing little benefit of applied P beyond the year of application and only a small amount of N from the previous
manure applications. We are examining cross media effects: nitrous oxide emissions and nitrate leaching from the manure bands using chambers and suction lysimeters. We are planning to start testing cross media effects from the sludge next year.

References
