Teaching Sustainable Soil Management: A Framework for Using Problem-Based Learning
Maja Krzic,* Arthur A. Bomke, Melanie Sylvestre, and Sandra J. Brown

ABSTRACT  Postsecondary institutions are currently developing and applying innovative curricula to meet the future demand for land managers and planners with a solid knowledge of soil science. The objective of this study was to describe and evaluate the University of British Columbia (UBC) Farm problem-based learning (PBL) case study within the upper level, undergraduate/graduate Sustainable Soil Management course. The UBC Farm case led to compilation of a student-generated data set that dates back to 2004 and allowed students to work in collaboration with the UBC Farm managers and staff. Preliminary student feedback indicated that the UBC Farm case was effective at presenting the impacts of agricultural management practices on soil chemical properties and overall soil quality concepts. In addition, students found the hands-on activities of soil sampling, data interpretation, and working in collaboration with the farm staff to be stimulating. Having the opportunity to involve students in data collection each year allows instructors to build depth into the case, to ask more complex questions, and to cooperate with the farm manager in focusing on specific issues of relevance to the farm that change over time. This educational approach could serve as a framework for using PBL within postsecondary soil science curriculum in ways that support both student learning and natural resource management.

Advances in our understanding of soils have contributed to actions that increase agricultural productivity and continue to play a vital role in resolving a variety of global issues such as climate change, food security, environmental regulation, and ecosystem services (Doran, 2002; Stocking, 2003; Janzen et al., 2011). Several international organizations, including the United Nations (UN Millennium Project, 2005; UN Development Programme, 2007) and Intergovernmental Panel on Climate Change (Hartemink, 2008) have highlighted the need for enhancement of soil science education and the provision of adequate soil information. As the importance of these issues continues to grow, it is essential that post-secondary institutions provide students with a strong foundation in soil science principles applicable to the context of current global change (Baveye et al., 2006; Collins, 2008). Some universities (e.g., California Polytechnic State University, Cornell University, University of Maryland) have reorganized their soil science curriculum (Baveye et al., 2006; Collins, 2008), creating new courses that focus on environmental issues (McCallister et al., 2005), and/or creating interdisciplinary soil science programs (Hansen et al., 2007). Many are also introducing student-centered educational approaches and learning technologies.

One of the approaches to enhance postsecondary soil science curricula is through adoption of the problem-based learning (PBL) instructional method; PBL originated from the medical school program at McMaster University, Hamilton, Ontario, in the 1960s (Barrows and Tamblyn, 1980; Barrows and Kelson, 1995) and it has spread to other areas of professional education (Duch et al., 2001; Thien et al., 2008). In PBL, student learning centers on complex, open-ended problem scenarios to encourage communication, problem-solving, critical thinking, collaboration, and self-directed learning skills (Barrows and Tamblyn, 1980). Students work in collaborative groups to identify what they need to learn to solve a problem. They engage in self-directed learning and then apply their new knowledge to the problem, and reflect on what they learned and the effectiveness of the strategies employed. The instructor facilitates and guides the learning process by answering questions and offering resources (Aspy et al., 2001; Thien et al., 2008).
Adoption of the PBL approach was one of the main features of the organizational change that took place within the Faculty of Agricultural Sciences at the University of British Columbia (UBC), Vancouver, Canada in late 1990s and early 2000s. At that time, the faculty was experiencing a decline in student enrollment and its structure fostered isolation among faculty members (Rojas et al., 2012). Moreover, the faculty was failing to address the larger agricultural and food issues within regional and global contexts. Hence, the time was right for an organizational restructuring, curricular revision, and adoption of new teaching approaches. The changes included dissolving all departments, reviewing courses and majors, training faculty members to use PBL techniques, discussing strategies to encourage participatory, learner-centered pedagogy, and creating a new integrative curriculum centered on sustainability. The restructuring also resulted in changing the faculty’s name from Agricultural Sciences to Land and Food Systems in 2005. Concurrently, instructors with responsibility for sustainable soil management initiated in 2004 an innovative approach to better integrate soil science teaching and research with local and global land-use issues, and to appeal to a broader student base in environmental sciences and forestry, in addition to students focused on agricultural land uses.

Table 1. List of the problem-based learning (PBL) case studies used in the Sustainable Soil Management course offered at the University of British Columbia (UBC), Vancouver.

<table>
<thead>
<tr>
<th>Course section</th>
<th>PBL case</th>
</tr>
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<tbody>
<tr>
<td>Soil physics</td>
<td>Impacts of soil rehabilitation on forest landings sites on soil quality in central British Columbia</td>
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<tr>
<td></td>
<td>Cattle grazing effects on grassland soils in southern interior of British Columbia</td>
</tr>
<tr>
<td></td>
<td>Irrigation system installation and its impacts on soil quality in Rajasthan, India</td>
</tr>
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<td></td>
<td>Soil erosion on sloping agricultural lands in Nepal</td>
</tr>
<tr>
<td>Soil chemistry</td>
<td>Effects of agricultural production on soil chemical properties at the UBC Farm</td>
</tr>
<tr>
<td></td>
<td>Designing soil mixtures for closure of the Vancouver Landfill</td>
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<tr>
<td></td>
<td>Soil mixtures used to cover Dunakeszi Landfill in Hungary</td>
</tr>
<tr>
<td></td>
<td>Uneven tree growth at a woodlot on northern Vancouver Island as affected by soil properties</td>
</tr>
<tr>
<td></td>
<td>Soil quality assessments of various community gardens in Vancouver</td>
</tr>
<tr>
<td>Soil biology</td>
<td>Cattle grazing effects on meso-fauna in grassland soils in southern interior of British Columbia</td>
</tr>
<tr>
<td></td>
<td>Soil macro- and meso-fauna on the forest long-term soil productivity sites in central British Columbia</td>
</tr>
<tr>
<td></td>
<td>Effects of timber harvesting types on soil microbial communities as determined on the long-term study sites near Campbell River on Vancouver Island</td>
</tr>
</tbody>
</table>

† During each course section, students chose one PBL case that they will work on during 4 weeks of group work.

In this article we describe the application of the PBL approach in the combined undergraduate and graduate-level course on Sustainable Soil Management, focusing on the UBC Farm case study. The UBC Farm PBL case study is one of 12 PBL cases in this course; it is used as an example since it integrates student collaboration with the farm managers and hands-on experience of soil data collection that led to compilation of a long-term student-generated data set.

**MATERIALS AND METHODS**

**Course Overview**

This project is situated in the context of a combined upper-level undergraduate and graduate level course on Sustainable Soil Management, offered by the Faculty of Land and Food Systems, UBC. The course is generally taken by 25 to 40 students majoring in Agroecology/Applied Biology, Forestry, Science, and Environmental Sciences. The overall course learning outcome is that students will be able to utilize physical, chemical, and biological soil quality indicators to assess the sustainability of land management practices in forest, agricultural, urban and constructed ecosystems.

The Sustainable Soil Management course builds from the soil quality concept, based on the assumption that an individual soil has the ability to properly function in a variety of roles (Doran, 2002). As Carter et al. (1997) have suggested, soil quality can be evaluated through a framework based on the following hierarchy: functions, processes, attributes or properties, indicators, and methods. Students enrolled in the Sustainable Soil Management course are asked to (1) develop a soil quality framework, (2) identify soil properties from the data set provided or generated to be used as soil quality indicators, and (3) assess if the specific land-use is degrading or enhancing soil quality. This task mimics the real-world assessment that a land manager carries out in evaluating a site for a specific land-use and is aligned with the PBL approach that learning is organized around investigation, explanation, and resolution of real-world problems (Barrows, 2000; Spronken-Smith, 2005).

The course content is divided into three segments: soil physics, soil chemistry, and soil biology. For each segment, there are several PBL case studies (Table 1), and students are given a chance to select a case study of the highest interest. Their preferences are taken into consideration by instructors when designating groups. During the course, each student works on three, 4-week-long PBL case studies. For 4 weeks, students work in groups (containing four to seven students) in a face-to-face classroom setting to address the learning outcomes of the PBL case. At the beginning of each case, students receive a handout containing background information about the study site, suggested references, and week-by-week learning outcomes and associated guiding questions. The two instructors are present in the classroom during group work sessions with the intent to ensure that each group is focusing on the most important learning issues and is on track toward solving their unique soil management problem.

At the end of the 4-week period, each group shares their findings with the entire class in an oral, group presentation. In addition, individual students are required to produce a 1000-word report detailing their learning with respect to the learning outcomes of a particular case. The report must also include a brief comparison of key soil science principles that were relevant for all the PBL case studies addressed during the 4 weeks. This last step was designed to reinforce the
notion that soil science principles are universal across ecosystems and represent a basis for sustainable soil management. It is also intended to encourage the students to learn from their peers.

The University of British Columbia Farm Problem-Based Learning Case Study

The PBL case study focused on the UBC Farm is part of the soil chemistry section of the Sustainable Soil Management course (Table 1). The overall learning outcome of the UBC Farm case study is to allow students to characterize the soil chemical environment to enhance soil quality, plant production, and long-term soil sustainability. Learning outcomes, tasks, and guiding questions specific for the UBC Farm case are outlined in Table 2.

Figure 1 illustrates the site currently occupied by the UBC Farm and its proximity to the rapid urbanization of UBC’s campus. Its original vegetation of second growth Douglas-fir (Pseudotsuga menziesii Mirb.), western hemlock (Tsuga heterophylla (Raf.) Sarg.), and western redcedar (Thuja plicata Donn ex D. Don) was cleared in late 1960s, and the soils have been manured, fertilized, limed, and irrigated since that time. The UBC Farm was reorganized into a teaching and production farm in 2001 when a vegetable crop rotation was initiated and detailed soil characterization done for each plot (Masselink, 2001). The Sustainable Soil Management course has contributed to those efforts by collecting soil samples and data since spring 2004.

As per the learning outcome for Week 1 of the UBC Farm case (Table 2), students reviewed background information on the climate, topography, and the dominant soil type at the case study site(s) as provided in soil survey reports (Luttmerding, 1984; Bertrand et al., 1991) and previous studies carried out at the UBC Farm (Lavkulich and Rowles, 1971). That review allows students to identify the key characteristics for crop production, including the abundance of rainfall during fall and winter months in contrast with the relatively dry summer months, flat topography, the presence of a naturally occurring very dense horizon at about 1 m depth within the soil profile, coarse soil texture (i.e., sandy loam to loamy sand), low organic matter content, and acidic soil pH. The dense horizon is known to impede drainage, which is especially problematic during the wet fall and winter months that are typical for this region. On the other hand, during the dry summer months, these coarse-textured soils can become quite dry due to their low water holding capacity.

Based on the information gathered during the site background research, students consider which soil chemical parameters to assess. In addition, they also develop a sampling design, giving consideration to sampling depth, and the number of subsamples to collect and composite. At the end of Week 1, students sample plots selected by the

<table>
<thead>
<tr>
<th>Week</th>
<th>Learning outcome</th>
<th>Student tasks</th>
<th>Guiding questions</th>
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<tbody>
<tr>
<td>1</td>
<td>Students will be able to explain soil formation factors and processes, focusing on the main soil type (Bose Humo-Ferric Podzol) at the UBC Farm.</td>
<td>Review background information on the biophysical characteristics (topography, climate, parent material) of the UBC Farm, including the main soil type, the Bose Humo-Ferric Podzol. Gain basic understanding of soil quality concept. Share individual learning with group members (ongoing for Weeks 1-4).</td>
<td>What are the key properties of Podzols? What are the key diagnostic features of the Bose soil for management considerations?</td>
</tr>
<tr>
<td>2</td>
<td>Students will be able to interpret long-term soil chemical properties obtained at the UBC Farm.</td>
<td>Review the long-term soil data obtained at the UBC Farm. In collaboration with the UBC Farm manager select plots for sampling and review past management practices on those plots. Sample selected plots at the UBC Farm. Prepare soil samples for laboratory analysis and send samples to the commercial soil testing laboratory. Identify the key soil quality indicators to be analyzed in the laboratory.</td>
<td>Soil chemical properties are derived from the complex interaction of the soil mineral and organic colloids, weathering processes, vegetation and past management. Given the information for the Bose soil, what are the key soil quality indicators?</td>
</tr>
<tr>
<td>3</td>
<td>Students will identify appropriate soil management within an organic farming practices framework.</td>
<td>Review current-year soil results Recommend soil management practices with emphasis on soil chemical properties, but including other relevant landscape and soil physical properties. Describe the general principals and management standards of Canadian organic production systems relevant to soil management at the UBC Farm. Develop a soil quality framework. Prepare for group presentation.</td>
<td>How do your (i.e., current-year) results compare to long-term data obtained at the UBC Farm? If your results differ from the long-term data, what are the implications for sustainable production at the Farm? How does the Farm’s compost quality relate to maintaining soil quality? How does the Farm’s policy of adhering to organic practices influence your interpretations of soil results and the resulting recommendations?</td>
</tr>
<tr>
<td>4</td>
<td>Students will be able to synthesize information gathered in the UBC Farm PBL case and present it in both oral and written formats.</td>
<td>Prepare a summary report for the UBC Farm Student group presentations about key findings of the case study.</td>
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</tbody>
</table>
During Week 2 of the UBC Farm case, students focus on the long-term soil data set dating back to 2004 (Box 1) and identify general trends in soil chemical properties by comparing them to the typical properties of a Bose Humo–Ferric Podzol as reported in the soil survey (Luttmerding, 1984).

Replacement of the forest vegetation with agricultural crops and associated management practices since the 1960s have resulted in substantial changes of some soil properties. For example, soil organic matter in the A horizon increased from about 2% in a typical Bose soil under its natural vegetation (Luttmerding, 1984), to 6.5% as determined by Lavkulich and Rowles (1971) on the cultivated sites of the present day UBC Farm back in 1970, to 12 to 17% in 2013 (data not shown). An additional change caused by the annual additions of various organic amendments at the farm is the formation of a well-developed Ah<sub>1</sub> horizon ranging between 30 and 60 cm in thickness (Fig. 2b). Typically, a Bose soil under natural vegetation would have an Ah horizon of about 5 cm in thickness (Fig. 2a). This increase in soil organic matter within the A horizon is of particular importance for crop production on these coarse-textured soils characterized by a low water and nutrient holding capacity. The increase of the soil organic matter is also accompanied by an increase in total soil N, from 0.03% in a typical Bose soil (Luttmerding, 1984), to 0.19% as observed in 1970 on cultivated sites 10 years after their establishment (Lavkulich and Rowles, 1971), to 0.26 to 0.41% (data not shown) in 2013. Similarly, available P has increased from 33 ppm in a typical Bose soil (Luttmerding, 1984), to 90 ppm in cultivated sites in 1970 (Lavkulich and Rowles, 1971), to 103 to 231 ppm in 2013 (data not shown).

Box 1. Student-Generated Soil Data Set

Since 2004, students working on the UBC Farm PBL case have worked together with instructors and the UBC Farm’s manager in the selection and sampling of plots for soil chemical analysis and data interpretation. Plot selection is based on: (1) how long since a plot was last sampled, (2) are there any pressing management issues that need to be resolved during the upcoming growing season, and (3) were there any unusual plant growth patterns observed during the previous growing season. To date, every plot used for commercial production at the UBC Farm has been sampled between three and five times for the following soil properties: pH, electrical conductivity, organic matter, total N, available P, K, Ca, Mg, and trace elements (Cu, Zn, Fe, Mn, and B). Students determine how to sample soil from the plots with guidance from the course instructors. A random sampling design is used to collect samples from 0-15 cm depth; a composite sample is generated for each plot; and samples are analyzed by the same, local commercial testing laboratory using standard soil analytical methods (Carter and Gregorich, 2008). The same sampling protocol and analytical methods have been used in all years since 2004.

Currently at the UBC Farm there are 27 plots, and ideally, each plot would be sampled every year, but the financial and time constraints of sampling are too high for the Farm staff to handle. This prompted us to incorporate the UBC Farm PBL case study into the Sustainable Soil Management course, which in turn led to development of the student-generated soil data set. Since 2004, a total of 129 soil samples has been collected and analyzed; 73 samples (or 57%) were provided by the Sustainable Soil Management course. The involvement of students from the course in soil sample collection and data interpretation has provided a solution for both the logistics of data collection and the interpretation of soil data for the UBC Farm.

UBC Farm manager and send their samples to a local soil testing laboratory for analysis.

Fig. 1. Map of the University of British Columbia (UBC) Farm.
Due to on-going liming applications pH of the UBC Farm soil has increased from 4.7 (Luttmerding, 1984) to 5.7 to 6.5 in 2013 (data not shown).

In Week 3 students compare their own data, which they would have just received back from a soil testing laboratory, to the long-term trends. In addition, they also consider management practices at the UBC Farm, keeping in mind the farm’s policy of adhering to organic farming practices. Student assessment of the data highlights consistently high soil organic matter levels over time associated with the ongoing application of organic amendments. Additionally, students assess soil nutrient levels with specific crops in mind. For example, crops such as brassicas, berries, and potatoes have greater requirements for K than corn and cucurbits (plants from Cucurbitaceae family such as zucchini, pumpkins, watermelons, and cucumber). Available K levels are carefully monitored to ensure that K demanding crops have sufficient amounts to support good yields and crop quality. Soil pH was also considered relative to lime requirements for fields with pH < 6.0, and students suggested liming where appropriate.

In Week 4, in addition to giving a group presentation and preparing a term paper, students working on the UBC Farm case prepare a summary report for the farm’s staff. That report includes soil data interpretation and assessment of management practices. For example, students recognized the challenges related to high leaching potentials of nutrients (e.g., K, Mg, and B) in these coarse-textured soils located in a humid maritime climate, and acknowledge the contribution of organic matter management practices in enhancing nutrient holding capacity at the UBC Farm. Additionally, students have noted the importance of considering pH ranges for specific crops within crop rotation design and the timing of amendment applications. For example, students suggested that potatoes, which can tolerate much lower soil pH than most other crops, could be incorporated in the rotation as long as possible after liming on these naturally acidic soils.

Feedback Compilation

Feedback regarding the UBC Farm case was obtained in spring 2014 from all stakeholders involved—UBC Farm staff, students, and course instructors. Feedback from farm staff (director, field manager, academic coordinator, and production coordinators) and course instructors was obtained through one-on-one, 15-minute interviews. Student feedback on the effectiveness and appeal of the UBC Farm PBL case (Table 3) was obtained using an anonymous online questionnaire combining quantitative questions (on a Likert five-point scale) and open-ended questions (i.e., total of 10 questions). The feedback form included the following four open-ended questions: (1) What did you like the most about the UBC Farm case study? (2) Was there anything that you did not like about the UBC Farm case? (3) Is there something that you would like to add or change to the case? and (4) What would you say you learned from participating in the UBC Farm case study? All students (total of 17) who participated in the UBC Farm case in 2012, 2013, and 2014 were invited to participate in the survey and the response rate was 71% (n = 12). The relatively low number of the student participants was reflective of course enrollment and PBL requirements for small student groups. The survey form was modeled after design-based research principles (Wang and Hannafin, 2005), which provided participants with a complete disclosure of the survey intentions (i.e., case description, its learning outcomes, and the overall study objective).

RESULTS AND DISCUSSION

Students’ Feedback

All students who participated in the survey agreed (either strongly or mildly) that the UBC Farm case was effective at presenting the impacts of agricultural management practices on soil chemical properties and overall soil quality concepts (Table 3). This was very encouraging since student confidence in the presentation of concepts is crucial for their learning (Thien et al., 2008). This response also gave us confidence that the case was appropriately designed, since one of the main challenges within PBL is achieving a well-designed problem scenario. Scenarios that contain inadequate information within the problem for the students to work with, lack of clear triggers allowing students to develop rationales, lack of relevance to the students, and unrealistic problems have all been identified as obstacles to PBL adoption (Wells et al., 2009). Soil sampling and data interpretation required by the UBC Farm case were found to be helpful by all student respondents (Table 3). All students agreed (either strongly or mildly) that these practical
Table 3. Student (n = 12) feedback gathered through an anonymous online survey regarding the University of British Columbia (UBC) Farm problem-based learning (PBL) case study used in the Sustainable Soil Management course offered at UBC, Vancouver.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly agree</th>
<th>Mildly agree</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>The UBC Farm case study was effective at presenting the impacts of agricul-</td>
<td>5</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>tural management practices on soil chemical properties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The UBC Farm case study was effective in demonstrating impact of inherent</td>
<td>10</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>soil properties on soil quality and management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The UBC Farm case study was helpful in facilitating my understanding of soil</td>
<td>8</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>quality concept</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil sampling enhanced the appeal of the soil quality assessment</td>
<td>10</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Soil data interpretation was helpful in allowing me to understand importance</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>of soil chemical properties for crop production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collaborating with the UBC Farm manager helped me understand the main soil</td>
<td>8</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>quality issues at the Farm</td>
<td></td>
<td></td>
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† The feedback form also included the options “strongly disagree” and “mildly disagree,” however, no respondent chose either option for any of the questions. Consequently, those two response options are not shown in this table.

Aspects of learning about soil quality and management were helpful. The majority of students also found collaboration with the farm manager helpful in understanding the main soil quality issues. The feedback is well-aligned with findings of Schmidt (1983), who showed that PBL increases student motivation, because students feel empowered to have an impact on the outcome of the case study and are invested in the solution to the problem being embarked upon. Schmidt (1983) also argued that there are increased opportunities for students to elaborate on their own knowledge base through more active involvement and verbalization within a group (team) setting.

Based on the open-ended feedback responses, it was discovered that 7 out of 12 respondents found being able to visit the UBC Farm and interact directly with staff to be the most useful component of the study case. Five students also pointed out that they appreciated collecting soil samples at the UBC Farm and contributing to the generation of a long-term data set, which instilled them with a sense of worth in being able to apply their newly acquired knowledge and skills. One student commented that “this [working in collaboration with farm staff] is something that only a limited number of undergraduate courses provide to students.”

When asked “Was there anything you did not like about the UBC Farm case?” about half of respondent stated that data set was a bit overwhelming and challenging to understand in the amount of time provided for the case. Respondents commented on the complexity of the case study in which they had to learn about various plant nutrients, their effects on plant growth in general, and specific nutrient requirements of several types of agricultural crops grown at the UBC Farm. However, students also pointed out that they understood that is often the nature of a real-world data and they appreciated the challenges brought by the case. Four students indicated that they would have appreciated having additional practical aspects (e.g., calculations of fertilizer and lime rates) included into the farm case study.

In the response to the question “What would you say you learned from participating in the UBC Farm case?” two students who participated in the survey brought up an interesting point regarding the current background of undergraduate students in soil and agricultural sciences. Many students no longer come from a farm background and have limited practical experience. Consequently, learning activities such as the UBC Farm case provide students with the opportunity to gain hands-on experience and a deeper understanding of the whole plant–soil system. As one student mentioned “to see the whole picture helps me assimilate the material covered in the course.” For three students who are planning to go into farming, the UBC Farm case gave them the opportunity to explore long-term trends in soil properties due to management practices, and to consider similar soil monitoring on their farms in the future. “The case taught me about the importance of keeping good records as a farmer to really understand how the management is affecting the soil,” said one student.

The University of British Columbia Farm Staff’s Feedback

The student-generated soil data set and interpretations made by students under course instructors’ guidance have been invaluable to the UBC Farm. The UBC Farm managers and staff have varied levels of soil science knowledge, and having a consistent and reliable source of data and interpretation is extremely important. Over the years, students enrolled in the Sustainable Soil Management course have come up with numerous suggestions, bringing new ideas for modified management practices at the farm. As the farm manager pointed out, the Sustainable Soil Management course is unique among all the courses carried out at the farm, since it allows students to be directly involved in numerous activities ranging from field sampling, to data interpretation and the development of recommendations based on the multifaceted information gathered.

Probably the most valuable contribution to the UBC Farm brought about by the involvement of the Sustainable Soil Management students is the development of the coherent long-term data set (Box 1) that farm managers can use when making decisions toward sustainable agricultural practices. To be able to review more than 10 years of consistent soil data allows the farm manager to observe soil quality improvements under the farm’s practices. Without the student-generated data set the UBC Farm would either have to dedicate a portion of its very limited resources to soil sampling or to try to make farming decisions with limited information on soil quality.
Another benefit of having students working on the UBC Farm case study is to open an avenue for students to learn about the farm. Even though the farm is located on the UBC campus, the site is still spatially removed from the numerous other UBC buildings and areas frequented by students. Hence, not all UBC students are aware of the farm’s existence. The Sustainable Soil Management course is taken by students from several faculties and some of those students have not visited the farm prior to this course. Having students work closely with the farm manager and other staff members helps instill a sense of belonging and community for both groups. As a teaching, research, and community engagement production farm, the UBC Farm thrives on student involvement. The farm manager commented that he has observed over the years that students who were involved in experiential learning projects such as the UBC Farm PBL case tend to be more likely to return to the farm either as volunteers or interns.

The farm manager and other staff members have expressed their gratitude for enhanced visibility of the UBC Farm brought through students’ presentations at workshops and conferences organized by various local professional and scientific societies. For example, students enrolled in the Sustainable Soil Management course are required to attend the annual conference of the Pacific Regional Society of Soil Science where they present key findings of the PBL case studies they worked on. Through those student presentations members of the non-UBC community are given the opportunity to learn about the UBC Farm and its activities.

**Instructors’ Feedback**

The UBC Farm case study is a rewarding teaching opportunity for the instructors allowing them to observe their students gather valuable knowledge and skills needed in a variety of real-world professional settings (e.g., farm management, private consulting, policy development). Learning an approach rather than getting the “right answer” is complex, but enhances students’ career preparation. The instructors find this case particularly interesting as it involves field work and the interpretation of data, which may or may not show clear trends. Typically, PBL case studies are based on existing, preselected data sets. The UBC Farm case, on the other hand, has no known outcome prior to the in-class data interpretation. No government or university researchers have previously assessed the data and there are no written journal articles or published reports focused on the data collected. This makes the UBC Farm PBL case challenging, but at the same time it is a relevant and motivating teaching and learning opportunity. The UBC Farm case incorporates characteristics of a successful PBL case study as noted by Arthur and Thompson (1999), namely undetermined outcome, specific focus, complex content, and representation of multiple stakeholders’ interests. The farm case experience is also in accordance with findings of several studies (Barak and Dori, 2005; Herrington, 2006) that inclusion of real-world scenarios into postsecondary curriculum has positive effects on student learning.

The format of the UBC Farm case and the student generated data (2004–ongoing) permits course instructors to contribute to the UBC Farm’s activities and decision making process. This is in contrast to our course experience with community garden projects where no background information is available and long-term sampling is not contemplated. Generating data at a single point in time is useful for students to assess short-term management but no trend analysis and only a limited assessment of sustainability is possible. The contrast between the two cases becomes apparent when student PBL groups present their findings, and individual students’ written reports compare and contrast the findings and learnings from all of the cases in the soil chemistry component of the course.

Having the opportunity to involve students annually in data collection allows instructors to build depth into the case, to ask more complex questions, and to cooperate with the farm manager in focusing on specific issues of relevance to the farm which change over time. Sustainable soil management must be more than a single year’s snapshot and the student generated data set at the UBC Farm gives students an opportunity to participate firsthand in a realistic assessment of agricultural sustainability.

**CONCLUSIONS**

There is an ongoing need for natural resource professionals with a solid understanding of sustainable soil management. One way to train those professionals is through incorporation of the PBL approach and real-world scenarios into soil science curriculum. To better integrate soil science teaching with local and global land-use issues and to stimulate students’ interest in the discipline of soil science, the Sustainable Soil Management course exposes students to practical experience through a variety of PBL case studies. The UBC Farm case study stands out among all cases used in this course, since it allows students to collect and interpret soil data and to work in a close collaboration with the staff of the UBC Farm. Another unique feature of this case study is the student-generated soil data set collected by 11 (and counting) cohorts of students who have taken the Sustainable Soil Management course. The data set is used both in the course mentioned above and by the UBC Farm managers in making ongoing decisions about agricultural practices.

Student feedback about the UBC Farm PBL case study was generally positive and it showed that students felt the farm case addressed the overall learning outcome to be able to characterize soil chemical properties. Of the feedback gathered, some common responses arose indicating certain shortcomings in the content for the farm case including the complexity of information and data provided. Students suggested that having more background information at the beginning of the case would remedy this situation. Furthermore, the students’ feedback also showed strengths of the UBC Farm case as students found its hands-on activities of soil sampling, data interpretation and working in collaboration with the farm staff to be stimulating. The majority of students found the long-term data set generated by the farm case to be a valuable learning opportunity to grasp the soil quality concepts covered in the Sustainable Soil Management course. The involvement of students in data collection over time has allowed instructors to add depth to the PBL case and to focus on emerging issues at the farm. The student generated data set if the UBC Farm case is particularly valuable for students’ and the farm manager’s evaluation of agricultural practices and development of sustainable soil management. Consequently, other teaching farms associated with postsecondary institutions might want to consider involving students and course instructors in long-term monitoring and data generation.
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