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Inventory of Norwegian grain production

Data from three average- and three high yielding cereal farms located in the major grain producing areas of Norway

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Inventory of Norwegian grain production: Data from three average- and three high yielding cereal farms located in the major grain producing areas of Norway

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Sammendrag:

I søk etter bærekraftige metoder for matproduksjon er kunnskap om miljøeffekter fra slik produksjon essensiell. Livssyklus-analyse (LCA) representerer en moderne metode for å identifisere «hotspots» for utslipp langs produksjonskjeden. Målet med vårt arbeid har vært å samle nødvendige data for å kunne foreta en slik LCA analyse av norsk kornproduksjon. Data for selve kornproduksjonen presenteres på gårdsnivå i denne rapporten. Vi har tatt for oss tre viktige områder der det drives kornproduksjon. Det gjelder Oslofjordområdet, Mjøsområdet og området rundt Trondheimsfjorden. Fra hvert område er det valgt ut to gårdsbruk; ett bruk med gjennomsnittlige- og ett bruk med høye avlinger. Informasjon om drift og avlinger på de gjennomsnittlige brukene er framskaffet via intervju med lokale rådgivere (Norsk Landbruksrådgiving), og ved å bruke generelle produksjonsråd samt data fra åpne kilder, slik som SSB. Informasjon om forhold på bruk med høye avlinger er hentet fra gårdbrukerne direkte. Rapporten inneholder også en beskrivelse av hvordan et utvalg miljøpåvirkninger kan beregnes. Resultater fra selve LCA-analysene er publisert separat.

Summary:

In the pursuit for sustainable food production, knowledge of the environmental impact from such production is essential. Life cycle assessment (LCA) represents a modern method to identify hot-spots for emissions along the production chain. The goal of the present work was to obtain data that are needed in order to perform a LCA on Norwegian grain production. In this report, data on the actual cereal production are presented on farm-level. We have considered the three most important regions for cereal production in Norway; the areas surrounding the Oslofjord, lake Mjøsa and the Trondheimsfjord. Within each region we have selected two farms; one farm with average yields and one with high yields. Information on management and yields on the average farms are obtained through interviews with local farm advisors (NLR), and from general recommendations and open data sources, such as Statistics Norway. Information on the high-yielding farms was taken directly from the farmers. This report also contains descriptions on how selected environmental impacts may be estimated. The results of the actual LCA are published elsewhere.

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1. FOREWORD

Understanding the environmental impacts associated with our food production and consumption is a prerequisite for identifying pathways towards a sustainable future. In order to consider the overall environmental impacts of a certain food production system, it is recommended to include the whole production chain and quantify the various environmental impacts per unit produced. Life cycle assessment (LCA) is so far the most developed/well adapted product-oriented assessment method for this purpose. The goal of the present work was to obtain data that are needed in order to perform a LCA on Norwegian grain production, a so-called inventory.

The present inventory is part of the project “Environmental impact and resource use efficiency of selected food production chains in Norway – a life cycle assessment (LCA) approach”, which focuses on environmental impacts and resource use efficiencies related to important food production chains in Norwegian agriculture. The project is funded by the Norwegian Research Council (program “Bionær”).

The inventory contains information on the management of three average– and three high yielding, grain-producing farms with conventional management in Central, Central Southeast and Southeast Norway, and it describes the methodology used to calculate the environmental emissions occurring on the farms.

The results of the LCA following this inventory is so far published in Roer et al. (2012), Korsaeth et al. (2013a) and Korsaeth et al. (2013b).

2. Table of content

3. GENERAL CONSIDERATIONS

3.1 Farm selection

Grain production in Norway is mainly performed in southern Norway, and is concentrated in three distinct regions. These include areas around the Oslofjord in the southeast (SE) and Lake Mjøsa in central southeast Norway (CSE), and the Trondheimsfjord region in central Norway (C). Grain production in all regions is mainly performed on soils developed either on morainic till overlying Cambro-Silurian limestone and shale, or on marine clays deposited at the end of the Weichsel ice age. The former are mostly loams, and the latter silty clay loams. When selecting the cereal farms, we used the assistance of the local agricultural advisory offices (The Norwegian Agricultural Extension Service). We selected one average- and one high yielding farm located on the main soil types in each of the three regions. Only farms dominated by grain production were selected. Other (minor) crops being present in the crop rotations (Farm 2 and 4) were neglected, as only activities related to grain production were considered here. The average yielding farms were further selected so, that their yield levels and relative distribution of the cropped area of each cereal crop were similar to those of the region averages. The high yielding farms were selected among farms obtaining yield levels well above the region averages, using their actual crop area distribution, respectively.

3.2 System boundaries, functional units and allocations

The physical system boundary is the outskirts of the farm itself and contains the fundamental elements (soil, buildings and machinery) and the management used in the production of cereals. We quantified all major inputs to the system, such as mineral fertilizer, pesticides, diesel and oil and their transport from the store to the farm, along with all major losses from the system, such as gaseous losses and losses of soil and nutrients via the water pathways. The emissions of climate gases (CO_2 and N_2O), the erosion and eutropication (of soil, N and P) and acidification potential resulting from field processes on the farm are calculated as described below.

The inventory starts after harvest of the preceding crop and ends after the harvest of the crop in question. The energy use and related emissions of the on-farm drying of the harvested grain is, however, included.

The *functional unit* is one hectare (ha): Diesel consumption is given in litre per ha while greenhouse gas emissions (CO_2 and N_2O) are expressed as kg CO_2 equivalents per ha. The acidification potential is given as kg SO_2 equivalents per ha and losses of soil, phosphorous and nitrogen is given in kg per ha. Greenhouse gas emissions and acidification potential is calculated separately for all cereal crops included (winter- and spring wheat, barley and oats), with the functional units being per ha winter- and spring wheat, barley and oats, respectively. For grain drying, the functional unit of electric energy consumption is ton grain. The ha-based data may easily be transformed into the functional units of one kg barley, spring wheat and oats at the farm gate, by dividing the data by the respective ha-yields specified in this inventory.

No *allocations* of input, management or environmental impact between grains and straw were made in this work since the straw is assumed ploughed under and thus represents no additional crop/product.

3.3 Environmental impacts

The environmental impact of grain production is addressed using the indicators shown in Table 1. The indicators are presented as yearly means per ha and the emissions are routed to a common pool named "Field emissions".

Table 1. Indicators of environmental impact assessed in this inventory.

Indicator	**Factors/compounds considered**
Energy consumption	Diesel, oil and electricity
Greenhouse gas emissions	CO_2, N_2O
Erosion and eutrophication	Soil loss, NO_3, P
Acidification	NH_3, NO_X, SO_2

3.3.1 Energy consumption

The diesel requirement for the field work processes was either set in accordance with the farmers own consideration or calculated. For calculation, we used a stepwise procedure. In the first step we used a Danish model “Drift” (Nielsen and Sørensen, 2010) to find the number of man hours needed to perform the various operations with the available equipment under the given conditions. We used mean field sizes (with a polygonic arrondation) and transport distances that were in accordance with those found on the farm in question. Model default values were considered reasonable as driving speed. Secondly, we decided whether the workload was light, medium or hard, and calculated the diesel needed per hour by using conversion factors 0.12, 0.19 and 0.25 ltr diesel per kW motor effect respectively (Romerike Landbruksrådgiving, 2010). The diesel requirement per ha was then found by straight forward calculation and compared with values found in literature.

Diesel consumption related to within-farm transport was calculated separately. We considered all transport on-farm as easy work (0.12 ltr diesel per kW) and assumed that the average speed was 20 km per hour. Within-farm transport covers the driving between farm buildings and field before and after each field working session, where the number of sessions is calculated from area and the specific process efficiency. During spraying, we considered the session to last until the sprayer was empty (using 200 ltr per ha as a mean doseage). During sowing and split fertilization the size of the seed/fertilizer tank was considered determinant for session length (using 220 kg seeds vs. 170 kg fertilizer per ha). Transport of treshed grains was simply calculated from the assumption that the trailers could contain the grain yield from 2 ha.

The consumption of *lubrication oil* was considered proportional to the diesel consumption (Dalgaard et al., 2001) and set at 0.62 % of the diesel consumption (Refsgaard et. al. sited in Dalgaard et al., 2001).

3.3.2 Greenhouse gas emissions

Global Warming Potentials is a metric making it possible to compare further climate impacts of emissions of long-lived climate gases. The emission of 1 kg of a compound is related to 1 kg of the reference gas CO_2 and expressed as kg CO_2 equivalents. Values are taken from the IPCC report (IPCC, 2006).

The CO_2-emissions considered here are direct emissions from liming, net mineralization of soil organic C as a result of management, and CO_2-emissions from diesel consumption attributed to crop management (soil tillage, crop treatment and harvest).

Liming: The annual lime requirement on all agricultural land on all farms is set to 250 kg CaO ha^{-1}, calculated from commonly used equations (Franzefoss, 2010). The calculations account for leaching/runoff losses (150-300 kg CaO-eq.) and acidification effects of fertilizer (80-100 kg CaO-eq.), precipitation (10-30 kg CaO-eq.) and "other acidifying factors" (20-50 kg CaO-eq.). Hence, the annual requirement of lime depends on the CaO content of the product used. The average annual CO_2-emissions from lime application are calculated as if the limestone is added each year, in accordance with IPCC (2006, Equation 11.12):

Annual CO_2-emissions$_{Liming}$ = M_{Lime} x EF_{Lime}

where M_{Lime} is the annual amount (requirement) of limestone or dolomite, and EF_{Lime} is the emission factor for the product in question. We used $EF_{\text{Limestone}} = 0.12$ and $EF_{\text{Dolomite}} = 0.13$.

Mineralization of soil organic C: Changes in SOC were estimated by model simulation. We used the ICBM model (Andrén et al., 2004), where we selected the change in the 10th year of the respective crop rotations (assuming all crops to be present each year) as a proxy of the current situation of the addressed cropping systems, but avoiding effects caused by model initialization in the first years of the model run.

Briefly, ICBM is a two-compartment model, representing young (Y) and old (O) soil carbon, respectively, with the corresponding decay rates k_Y and k_O. The decay rates, which were by default 0.8 yr^{-1} (k_Y) and 0.006 yr^{-1} (k_O), were adjusted by a daily farm specific decomposer activity factor (r_e), which is a multiplicative index describing the relative effects of soil moisture (r_W), soil temperature (r_T) and a cultivation factor (r_C). The cultivation factor was set to 1, which is the default value for an arable, cereal-dominated system (Kätterer et al., 2008). Daily products of r_W x r_T were calculated for six farms with cereal production in each of the three regions for the period 1980-2009 (Skjelvåg et al., 2013), from which we used the regional averages (i.e. the average for six farms within each region) for the period 2000-2009. The ICBM model was originally parameterized using a long-term (1956-1990) dataset from Ultuna, Sweden, where r_W x r_T was, for convenience, set to 1.0 for a N fertilized treatment with mainly spring cereal crops (Andrén and Kätterer, 1997). Hence, the r_W x r_T products used in the current study had to be normalized in order to use the original model parameterization, as described by Bonesmo et al. (2012). The final, normalized, regional decomposer activity factors (r_e) used were 1.21, 1.56 and 1.28 for the areas CSE, SE and C, respectively.

Diesel consumption: Diesel consumption is specified for each farm and the conversion factor from diesel to CO_2 is 2.6391 (kg CO_2 ltr^{-1} diesel) (National Energy Foundation, 2010).

Emissions of N_2O and conversion into CO_2-equivalents were estimated using the IPCC (2006) framework, which comprises estimates for both direct emissions and two pathways of indirect emissions (see fig. 1). Direct N_2O emissions were calculated as 1 % of the total N additions from mineral N fertilizer (F_{SN}), N in crop residues (F_{CR}) and N mineralization associated with loss of SOC (F_{SOM}), assuming a C:N ratio of 10, without any correction for soil moisture and temperature conditions.

Annual $N_2O_{direct} = (F_{SN} + F_{CR} + F_{SOM}) \times EF_1$,

where EF_1 is the emission factor for N_2O emissions from N inputs (EF_1 = 0.01 kg N_2O-N kg^{-1} N).

The first indirect pathway for N_2O emissions was the volatilization of N as NH_3 and oxides of N (NO_x), and the deposition of these gases and their products NH_4^+ and NO_3^- onto soils and the surface of lakes and other waters. It was assumed that 10 % of the N applied as mineral fertilizer was volatilized (as NH_3 and NO_x), and that 1 % of the volatilized (and re-deposited) N would be emitted as N_2O-N (IPCC, 2006).

Annual $N_20_{atmospheric\ depositions} = (F_{SN} \times Frac_{GASF}) \times EF_4$,

where $Frac_{GASF}$ is the fraction of mineral fertilizer that volatilises as NH_3 and NO_x ($Frac_{GASF}$ = 0.10 kg (NH_3-N + NO_x-N) kg^{-1} N applied), and EF_4 is the emission factor for N_2O emissions from atmospheric deposition of N to soils and water surfaces (EF_4 = 0.010 kg N_2O-N kg^{-1} (NH_3-N + NO_x-N) volatilised).

The second indirect pathway was the leaching of N, as some of this N may be nitrified or denitrified in the groundwater, in riparian zones, in ditches, streams and rivers and in estuaries (and their sediments). In accordance with IPCC (2006), we assumed that 0.75 % of the leached N was lost as N_2O-N.

Annual $N_20_{leaching}$ = (N leaching+ N runoff) x EF_5,

where EF_5 is the emission factor for N_2O emissions from N leaching and N runoff (EF_5 = 0.0075 kg N_2O-N kg^{-1} (N leaching + N runoff)).

The N_2O-emissions were converted into CO_2-equivalents by using a conversion factor of 298.

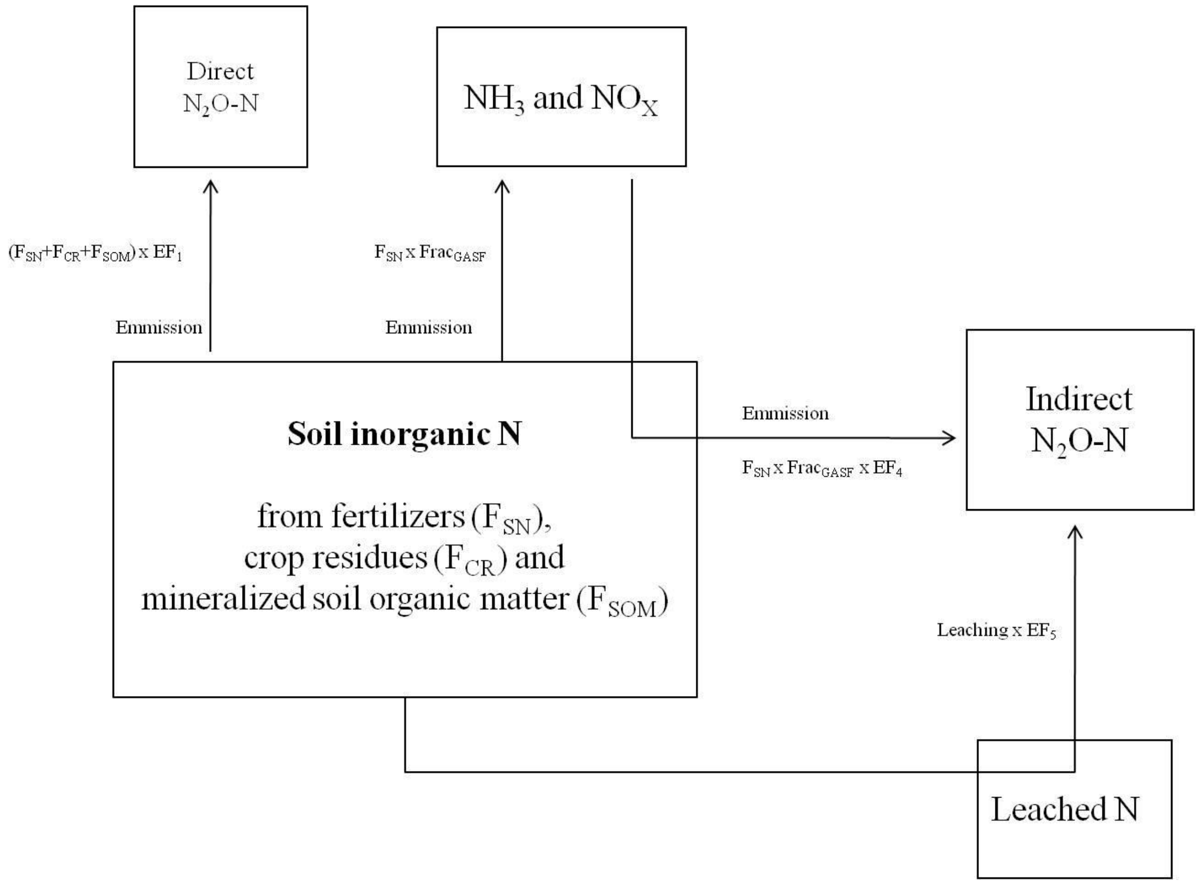

Figure 1. Nitrogen flows between compartments resulting in the emission of N_2O. Value of the different factors are given in the text.

3.3.3 *Erosion and eutrophication*

In the IPCC (2006) framework, N leaching is estimated as a fraction ($Nfrac_{LEACH}$) of the total N input to a system, with a default value of 0.3. In this study, we used a method especially designed to estimate farm-specific $Nfrac_{LEACH}$ under Norwegian conditions, based on long-term monitoring data from agricultural catchments, combined with farm-specific adjustments for runoff (i.e. the difference between annual precipitation and evapotranspiration) (Bechmann et al., 2012). Using this approach, we first selected the most representative catchment available from the Agricultural Environmental Monitoring Program (JOVA) (ibid) for each farm, taking into consideration both the dominant production type and the soil type within the catchment. Next we obtained the catchment specific data on $Frac_{LEACH}$ ($Frac_{LEACH\ catchment}$) and runoff ($R_{catchment}$). Farm specific runoff ($R_{farm\text{-}specific}$) was found by taking the closest point in a dataset consisting of 1 x 1 km grid values on long-term (1961-1990), annual average runoff, provided by the Norwegian Water Resources and Energy Directorate (2012). Finally, farm-specific $Frac_{LEACH}$ ($Frac_{LEACH\ farm\text{-}specific}$) values were calculated using the following equation:

$$Frac_{LEACH\ farm\text{-}specific} = Frac_{LEACH\ catchment} \times R_{farm\text{-}specific} / R_{catchment}$$

N leaching was calculated as the product of N input via fertilizer and $Frac_{LEACH\ site\text{-}specific}$ (in contrast to the ICPP approach, N from soil mineralization is not considered in the method of Bechmann et al. 2012).

Estimates of phosphorus losses through drainage and surface water were based on data from the JOVA monitoring programme (Bioforsk, 2010a). For farms in CSE, we calculated mean values from two data sources on P-losses: the Bye catchment (JOVA) and a long-term field experiment at Apelsvoll Research Centre near Kapp (Korsaeth, 2012), using the annual average for the period 2000-2009 at both locations. For farms in SE, we used data from the Skuterud catchment directly (annual mean for the period 1993-2009). Data from the Hotran catchment (annual mean for the period 1992-2009) were used for farms in C, but the P-losses were set to 30 % of those measured, in order to account for unusually high values in that catchment, probably caused by gully erosion observed along the river channel.

3.3.4 Acidification

Acidification is a consequence of acids (and other compounds which can be transformed into acids) being emitted to the atmosphere and subsequently deposited in surface soils and water. Acidification Potential (AP) is based on the contributions of SO_2, NO_x, HCl, NH_3 and HF to the potential acid deposition in the form of H^+ (protons), and is normally given in SO_2-equivalents (Heijungs et al., 1992) (Table 2):

Table 2. Acidification potentials.

Substance	Acidification potential (AP in kg SO_2-equiv./kg)
SO_2	1.00
NO_x	0.70
NH_3	1.88

In this report, we only consider compounds released to the atmosphere, not how they subsequently act acidifying on terrestrial systems. The acidifying compounds included (on farm) in this work were NO_x from diesel consumption and volatilized NH_3 and NO_x from fertilizer. Emissions of NO_x from diesel consumption were estimated on the basis of Li et al. (2006). The sum of volatilized NH_3-N and NO_x-N from fertilizer application was calculated following the IPCC framework described above. To separate between the two, the proportion of NH_3 volatilizing from fertilizer was calculated to 0.9 %, by considering the mean spring temperature and a specific emission factor for NPK compound fertilizer (EMEP/EEA, 2009, Tier 2).

4. INVENTORY OF TWO FARMS IN CENTRAL SOUTHEAST NORWAY

4.1 Area description

The Stange area is an important grain producing region at the Lake Mjøsa in Central Southeast Norway. The climate of the region is humid continental with a mean annual precipitation of 550 mm and a mean annual temperature of 3.8 °C and 12.4 °C in the growing season May – September. Farms in the region are mainly found on thick ablation moraines over cambrosilurian limestone and shale, where the major soil group is imperfectly drained brown earth (Oxiaquic Cryoboroll; USDA). Commonly, farms lie on the gentle slopes leading down to the lake Mjøsa, which constitutes the temporary recipient in this area, with a calculated residence-time of 5.6 years (Nashaug, 1999). So also for the selected farms which both lie along the shore of lake Mjøsa (120 masl). Water leaving Mjøsa runs through the river "Vorma" – further into "Glomma" and enters the outer region of the Oslofjord at the city Fredrikstad. The erosion risk varies from small to large, with most fields on the farm showing a small to medium erosion risk (NIJOS, 2010).

4.2 Inventory of Farm 1, average yield

The selected farm was 30.5 ha large and produced barley on 62 %, spring wheat on 28 % and oats on 10 % of its area in 2008. We assumed that the soil of the selected farm was a morainic loam with normal contents of plant available phosphorus and potassium (P-AL: 6-8, K-AL: 6-8; pers. com. Solberg[1]).

4.2.1 Infrastucture

Buildings and field arrondation. Norwegian farms include several buildings with functions related to ongoing activities, but also buildings of more historic value and human housing as

[1] Solberg, H., The Norwegian Agricultural Extension Service, Hedmark

well. Only buildings related to production of grains are considered here. Room for drying of grains (200 m^2) is included as is also a shed (300 m^2) for the machinery. Expected lifetime is 30 years.

The five fields are all located on the northwest side of the farm, on a gentle (1:17) slope down from the farm. Field sizes are 9.6, 3.8, 3.4, 3.9 and 9.8 ha (mean of 6.1 ha). Mean on-farm transport length is 0.45 km.

Machinery and mechanization. The machinery and equipment needed on a 30 ha farm in central southeast Norway is listed in Table 3.

Table 3. Machinery and equipment on Farm 1.

Machinery and equipment	"Size"	Weight (kg)	Expected lifetime (years)
New tractor	90 kW	5300	15
Old tractor	60 kW	4800	15
Very old tractor	45 kW	3800	15
Thresher 12 feet	95 kW 12 feet	7000	15
Reversible plough	4-furrow	1360	12
Leveller	4 m	1400	20
Loader		350	12
Stone rake	3 m	350	12
Seed drill (Rapid)	3 m	4000	10
Roller	4 m	1700	20
Sprayer	12 m	200	12
Disc spreader	10 m	200	10
Trailer, rough		2000	15

4.2.2 Management

The fields are ploughed in autumn (70 % of the total areal) or early spring (30 %). Thereafter follows levelling and simultaneous stone picking, a combined sowing and fertilization, drumming, first spraying (against weeds and insects), split fertilization (with OPTI-KAS), second spraying (against fungi and for growth regulation), threshing and spraying against couch in autumn after harvest (every third year).

All grain is transported to the grain dryer and dried after threshing. The approx. 150 tons of grain, with an average water content of about 18 % (17 % for barley, 19 % for wheat and oats; pers. com. Solberg[2]) coming into the dryer is dried down to 15 % water content. Barley is treshed first and 50 tons of barley are delivered to the mill (5 km distance) after drying, while the remaining 100 tons are stored on farm until prices are favourable, and then delivered to the same mill.

Crop rotation. The crop sequence is basically similar on all fields. On a cereal farm with 62 % barley, 28 % wheat and 10 % oats, barley-barley or oats-barley is presumably grown on poorer fields and wheat-barley on the best fields.

Grain yields and cereal varieties. The grain yields in central southeast Norway vary between cereal species and varieties, regions, farms and years. For yields, we chose to use the 10-year averages (1998-2007) for all farms in the Stange community, reported by Statistics Norway (www.ssb.no). All yields are reported with a moisture content of 15 % (standard), when not otherwise is specified. Average barley yields were 4690 kg ha^{-1}, with a minimum of 4120 to a maximum of 5760 kg ha^{-1} in the same period. The corresponding values for spring wheat and oats were 5460 kg ha^{-1} (5010-6100 kg ha^{-1}) and 4760 (3860-5360 kg ha^{-1}), respectively. Contents of energy were set to 19.0, 18.2 and 18.3 MJ kg DM^{-1} in oats, barley and wheat, respectively, based on the official Norwegian fodder nutrient table (Anonymous, 2009).

The cereal varieties were chosen on the basis of what is recommended for this area (Åssveen et al., 2010), and they were selected in order to spread out the threshing process somewhat in time. For barley, we chose two varieties (50 % of each). The two were an early 6-row barley variety “Tirill” and a later 2-row “Helium”. The rate of seeding aims at obtaining 450 viable seeds pr m^2 and will vary between years. In this work we have decided on using 180 kg “Tirill” and 220 kg “Helium” per ha. For oats, we chose the variety “Belinda” (220 kg ha^{-1}, 500 viable seeds m^{-2}). Both barley and oats are considered used in feed concentrate mixtures whereas spring wheat (variety “Zebra”; 220 kg ha^{-1}, 550 viable seeds m^{-2}) is considered used for human consumption (bread). “Zebra” was considered a good choice in this respect, since its baking quality (defined by the falling number) keeps high also under suboptimal conditions. Moreover, “Zebra” is quite resistant against Septoria. The protein content (% of

DM) in the chosen varieties (12.0 % for "Tirill", 11.8 % for "Helium", 11.9 % for "Belinda" and 13.9 % for "Zebra") was set in accordance with data from 31 relevant Norwegian field experiments (pers. com. Åsveen[2]). Seeds are transported from Moelv (50 km distance) by truck.

Fertilizers. Fertilization in barley and oats is assumed done simultaneously with sowing in spring. Spring wheat is split-fertilized with application both in spring and later in the summer. The amounts of fertilizer applied are based on general Norwegian recommendations (Bioforsk, 2010a) and specific values are given in Table 4. Fertilizers are bought in Hamar (20 km distance) and transported with tractor to the farm.

Table 4. Fertilizers and fertilization on Farm 1.

Cereal species	Area (ha)	Fertilizer type	Amounts (kg ha^{-1})	Comments
Barley	19	22-3-10	510	
Oats	3	22-3-10	445	
Spring wheat	8.5	22-3-10	420	
		OPTI-KAS	150	Split fertilization

Liming. Liming is done every 8 years with milled limestone (446 kg ha^{-1}; 52.4 % CaO- eq). This is done by contractors and the lime is transported from the nearest supplier (Brumunddal; 30 km distance) by tractor.

Pesticides. Practical spraying recommendations for the Stange area include spaying against weeds, fungi and insects as well as spraying with growth regulators. The spraying programme and active agents are shown in Table 5 (based on pers. com. Abrahamsen[3]). Pesticides are bought in Stange (5 km distance) and transported by car.

[2] Åsveen, M., Norwegian Institute for Agricultural and Environmental Research

[3] Abrahamsen, U., Norwegian Institute for Agricultural and Environmental Research

Table 5. General spraying recommendations on Farm 1.

	Reason for use	Trade name name	Active agent	Applied dosage
All fields	Couch gras[3]	Roundup	Glyphosate	2.8 $kgha^{-1}$
	Fungi on seeds	Celest FormulaM	Fludioxonil	10 g ha^{-1}
Barley				
1st spray	Weeds[1]	Starane XL	Fluroxypyr/Florasulam	70 g ha^{-1}/1.7 g ha^{-1}
	Insects[1]	Fastac 50	Alpha-Ceypermethrin	17 g ha^{-1}
2nd spray	Fungi[1]	Delaro	Trifloxystrobin/Prothicokonazol	88 g ha^{-1}/75 g ha^{-1}
	Growth regulator[2]	Moddus 250 EC	Trinexapacethyl	37 g ha^{-1}
Spring wheat				
1st spray	Weeds[1]	Starane XL	Fluroxypyr/Florasulam	70 g ha^{-1}/1.7 g ha^{-1}
	Insects[1]	Fastac 50	Alpha-Ceypermethrin	17 g ha^{-1}
2nd spray	Fungi[1]	Delaro	Trifloxystrobin/Prothioconazol	75 g ha^{-1}/88 g ha^{-1}
	Fungi[1]	Proline EC250	Prothioconazol	75 g ha^{-1}
	Lice [4]	Pirimor	Primicarb	50 g ha^{-1}
Oats				
1st spray	Weeds[1]	Starane XL	Fluroxypyr/Florasulam	70 g ha^{-1}/1.7 g ha^{-1}
	Insects[1]	Fastac 50	Alpha-Ceypermethrin	17 g ha^{-1}
2nd spray	Growth regulator[2]	Cycocel 750	Chlormequat chloride	750 g ha^{-1}

[1]Annually, [2]every 2nd year , [3]every 3rd year, [4]every 5th year.

4.2.3 Diesel consumption

The annual energy requirement for field work processes are shown in Table 6. The 90 kW tractor is used for ploughing and leveling, combined sowing and fertilization. The 60 kW tractor is used for spraying and split fertilization. The 45 kW tractor is used for drumming.

Table 6. Labour and diesel requirement needed on Farm 1.

Process	**Tractor (kW)**	**Workload (ltr h^{-1} kW^{-1})**	**Labour (h ha^{-1})**	**Diesel (ltr ha^{-1})**
Chemical fallow[1]	60	0.12	0.74	2.0
Ploughing	90	0.19	1.24	21.2
Levelling	90	0.19	0.45	7.7
Stone picking	90	0.19	0.2[2]	2.2
Liming[3]	120	0.19	0.29	6.6
Sowing and fertilization	90	0.12	0.78	8.4
Split fertilization	60	0.12	0.23	1.7
Spraying[4]	60	0.12	0.28	2.0
Drumming	45	0.12	0.44	2.4
Treshing barley	95	0.19	0.90	16.2
Treshing s. wheat	95	0.19	1.03	18.6
Treshing oats	95	0.19	1.13[2]	20.5

[1]Per spraying (every 3rd year), [2]value set, [3]every 8th year [4] per spraying.

4.3 Inventory of Farm 2, high yield

The selected farm in this area has an acerage of 88.7 ha. The soil of the selected farm was a morrainic loam (pH 6,5) with somewhat higher than normal contents of plant available phosphorus and potassium (P-AL: 8-10, K-AL: 15).

4.3.1 Infrastucture

Buildings and field arrondation. Room for drying of grains (200 m^2) is found on the farm, along with a shed (500 m^2) for the machinery. Expected lifetime of the buildings is 30 years.

The four fields are all located close to, and surrounding the farm. Field sizes are 30, 21, 20.7 and 17 ha (mean size: 22.2 ha). The average "on-farm" transport length is 0.4 km.

Machinery and mechanization. The machinery and equipment on Farm 2 are listed in Table 7.

Table 7. Machinery and equipment on Farm 2.

Machinery and equipment	"Size"	Weight (kg)	Expected lifetime (years)
New tractor	135 kW	5300	15
Old tractor	70 kW	5000	15
Thresher 24 feet	300 kW	15000	15
Reversible plough	5-furrow	1360	12
Leveller	5.5 m	1400	20
Loader		350	12
Stone rake	3 m	350	12
Seed drill (Rapid)	4 m	4000	10
Roller	6.2 m	1700	20
Sprayer	20 m	200	12
Disc spreader	20 m	200	10
Trailer, rough		2000	15

4.3.2 Management

The fields are ploughed in autumn (80 % of the total areal) or early spring (20 %). Thereafter follows levelling and simultaneous stone picking, a combined sowing and fertilization, drumming, first spraying (against weeds and insects), split fertilization (with OPTI-KAS), second spraying (against fungi and for growth regulation), threshing and spraying against couch in autumn after harvest (on two thirds of the farm yearly). Winter crops are fertilized in spring and summer (split application).

All the barley and approximately 70 % of the wheat are transported to the mill directly after treshing. The remaining is dried down to 15 % water content on the grain dryer on the farm. Water contents at harvesting are 17 % for barley and 18 % for the wheat.

Crop rotation. The crop sequence is basically similar on all fields. The rotation starts with either onions or oilseed rape. Winter wheat is grown thereafter and is followed by spring wheat and barley. Wheat is grown on approximately 45 % of the farm, barley on 17 % and autumn oilseed rape on 22 %. Additionally, 17 % of the area is rented to a neighbouring farm annually and grown with onions.

Grain yields and cereal varieties. The grain yields were quite high. Barley yields (variety "Tirill") were 6000 kg ha^{-1}. The corresponding values for spring wheat (variety "Demonstrant") and winter wheat (variety "Kuban") were 6500 and 6600 kg ha^{-1} respectively.

Seed for the coming season is mainly withdrawn from the yield and not treated with any chemicals. Approximately 20 % of the yearly need is, however, bought in Stange (5 km distance) and transported with a tractor to the farm.

Fertilizers. Fertilization in barley is done simultaneously with sowing in spring. Winter- and spring wheat is split-fertilized with application both in spring and later in the summer. The amounts of fertilizer applied are given in Table 8. Fertilizers are bought in Stange (5 km distance) and transported with a trailer to the farm.

Table 8. Fertilizers and fertilization used on Farm 2.

Cereal species	**Area (ha)**	**Fertilizer type**	**Amounts (kg ha^{-1})**	**Comments**
Barley	15	22-3-10	550	
Spring wheat	20	22-3-10	520	
		OPTI-KAS	170	Split fertilization
Winter wheat	20	22-3-10	520	
		OPTI-KAS	170	Split fertilization

Liming. Liming is done every 6 years with milled limestone (477 kg ha^{-1}; 52.4 % CaO- eq.). This is done by contractors (with a truck) and the lime is transported from the nearest supplier (Brumunddal; 30 km distance) by trailer.

Pesticides. Spraying is performed against weeds, fungi and insects and growth regulators are used regularly. The spraying program and active agents used are shown in Table 9. Pesticides are bought in Hamar (15 km distance) and transported by car.

Table 9. Spraying practices on Farm 2.

	Reason for use	Trade name	Active agent	Applied dosage (ha^{-1})
All fields				
	Couch gras[1]	Roundup	Glyphosate	1.4 kg
	Fungi on seeds[2]	Celest FormulaM	Fludioxonil	10 g
	Wild oats[3]	Axial 050EC	Pinoxaden	40 g
Barley				
1st spr.	Weeds[4]	Granstar Power	Tribenuron methyl/Mekoprop	10.7 g/800 g
2nd spr	Fungi[4]	Delaro	Trifloxystrobin/Prothicokonazol	120 g/140 g
	Insects[4]	Karate	Lambda-cyhalotrin	6.3 g
	Growth regul.[5]	Moddus 250EC	Trinexapacethyl	78 g
Spring and winter wheat				
1st spr.	Weeds[4]	Granstar Power	Tribenuron methyl/Mekoprop	10.7 g/800 g
2nd spr.	Fungi[4]	Proline EC250	Prothioconazol	176 g
	Insects [4]	Sumi Alpha	Esfenvalerate	15 g
	Growth regul.[5]	Moddus 250EC	Trinexapacethyl	78 g

[1]On 2/3 of the area every year, [2]on 20% of the seed used, [3]on 9 ha every year, [4] annually, [5]every second year.

4.3.3 Diesel consumption

The diesel requirement for the field work processes is shown in Table 10. The 135 kW tractor is used for ploughing, levelling and sowing. The 70 kW tractor is used for chemical fallow, split fertilization, spraying and drumming.

Table 10. Labour and diesel requirement needed for the field work processes on Farm 2 in Stange.

Process	Tractor (kW)	Workload (ltr h^{-1} kW^{-1})	Labour (h ha^{-1})	Diesel (ltr ha^{-1})
Chemical fallow[1]	70	0.12	0.24	2.0
Ploughing	135	0.19	0.94	24.1
Levelling	135	0.19	0.34	8.7
Stone picking	135	0.12	0.16[2]	2.6
Liming[3]	140	0.12	0.13	2.2
Sowing and fertilization	135	0.12	0.6	9.7
Split fertilization	70	0.15	0.12	1.3
Spraying[4]	70	0.12	0.24	2.0
Drumming	70	0.12	0.29	2.4
Treshing barley				14.0[5]
Treshing s. wheat				14.5[5]
Treshing w. wheat				20.0[5]

[1]Every 3rd year, [2]Value calculated, [3]Every 6th year, [4]per spraying, [5]Set similar to Farm4.

5. INVENTORY OF TWO FARMS IN SOUTHEAST NORWAY

5.1 Area description

A very important grain-producing area in Norway is found on the marine clays deposited south of the end morains running through Ås and Ski ("Ås-Ski-trinnet" deposited at the glacier margin 10200-10400 years ago). The agricultural area consists of several watersheds which drain out along the entire Oslofjord. The Ås area drains into Årungen and Bunnefjorden in the inner part of the Oslofjord and also south of Drøbak. Much of the Vestby area drains to the river Såna which runs into the Oslofjord at Son. Further inland, areas drain to Hobølelva and Glomma, which run into the Oslofjord at Moss and Fredrikstad, respectively The climate of the region is humid continental with a mean annual precipitation of 780 mm and a mean annual temperature of 5.4 °C and 13.4 °C in the growing season May-September. The distance to nearest marine environment, the Oslofjord is approximately 60 km. The erosion risk varies from small to medium (NIJOS, 2010).

5.2 Inventory of Farm 3, average yield

The selected farm (32.4 ha) produced barley on 8.6 ha (27 %), oats on 9.5 ha (29 %), spring wheat on 5.3 ha (16 %) and autumn wheat on 9.0 ha (28 %) in 2008. It belongs to Rakkestad community, is located 150 m above sea level and lies 1.5 km from Rakkestadelva which runs into Glomma at Brekke. The erosion risk on the farm is medium (NIJOS, 2010).

We assumed that the soil of the selected farm was a marine clay soil with approximately 30 % clay and contents of plant available phosphorus and potassium as normally found in this area (P-AL=8, K-AL=16; pers. com. Rostad[4]).

[4] Rostad, B. I., The Norwegian Agricultural Extension Service, SørØst

5.2.1 Infrastucture

Buildings and field arrondation. Room for drying of grains (200 m^2) is included as is also a shed (300 m^2) for the machinery. Expected lifetime of farm buildings were set to 30 years, which is commonly used elsewhere.

The farm buildings are located close by the five fields. Field sizes are 2.6, 11.4, 6.8, 4.6 and 7.0 ha (mean 6.48 ha) and the average transport distance on the farm 0.4 km.

Machinery and mechanization. The machinery and equipment needed on the farm are listed in Table 11.

Table 11. Machinery and equipment needed on Farm 3.

Machinery	**"Size"**	**Weight (kg)**	**Expected lifetime (years)**
New tractor	90 kW	5300	15
Old tractor	60 kW	4800	15
Very old tractor	45 kW	3800	15
Thresher 12 feet	95 kW	7000	15
Equipment			
Reversible plough	3-furrow	1000	12
Leveller	4 m	1400	20
Harrow	4 m	1200	20
Loader		350	12
Stone rake		350	12
Seed drill	3 m	2700	10
Roller	4 m	1700	20
Sprayer	12 m	200	12
Disc spreader	10 m	200	10
Trailer, rough		2000	15

5.2.2 Management

In this area, approximately 50 % of the fields are ploughed in autumn and the rest in early spring (pers. com. Rostad[5]). After ploughing follows levelling and simultaneous stone picking, harrowing and (in autumn) sowing of autumn wheat. In spring, the autumn wheat is fertilized using a disk spreader while spring barley is sowed and fertilized in combination. Drumming is performed after sowing. Through the summer comes a first spraying against weeds and insects, split fertilization with OPTI-KAS (in wheat), second spraying against fungi and for growth regulation, threshing and spraying against couch grass in autumn after harvest. More details about spraying are given in table 13.

At treshing, barley and oats contain approximately 15 % water while the wheat contains 17 %. According to the local advisory services, approximately 30 % of the grains are delivered directly to the nearest mill (in Degernes, 2.5 km distance) (pers. com. Rostad[6]). The rest (70 %) are dried and stored on the farm until prices are favourable. We assume that the entire barley crop is delivered directly.

Crop rotation. A reasonable crop rotation on a cereal farm with four cereal species is: barley, autumn wheat, oats and spring wheat.

Grain yields and cereal varieties. The grain yields in the area vary between cereal species and varieties, regions, farms and years. For yields, we chose to use the 10-year averages (1998-2007) for all farms in the Skiptvedt community, reported by Statistics Norway (www.ssb.no). All yields are reported with a moisture content of 15 % (standard), when not otherwise is specified. Average barley yields were 4090 kg ha^{-1}, with a minimum of 3570 to a maximum of 4770 kg ha^{-1} in the same period. The corresponding value for oat was 4470 kg ha^{-1} (4130-4860 kg ha^{-1}). Only gross data for wheat delivery exists in the databases of Statistics Norway. To split between spring- and autumn wheat yields, we made use of field experiments performed by Bioforsk in this area from 1998 to 2007 and split the total wheat volume in accordance with rexperimental data and documented areals (Korsaeth and Rafoss, 2009). For spring wheat we used a mean yield of 3880 kg ha^{-1} (3330-4440 kg ha^{-1}) and for autumn wheat 5210 kg ha^{-1} (4320-6170 kg ha^{-1}).

[5] Rostad, B. I., The Norwegian Agricultural Extension Service, SørØst

The cereal varieties were chosen on the basis of what is recommended for this area (pers. com. Rolstad[6]). For barley we chose the variety “Helium” and for oats “Belinda”. For autumn wheat we chose the variety “Mjølner” and for spring wheat “Zebra”. Seeding rates are commonly set at 230 kg per ha for all species in this area. Seeds are transported from Rakkestad (10 km distance) by tractor.

Fertilizers. Fertilization is considered done simultaneously with sowing in spring on the present farm. Autumn wheat is not fertilized at sowing in autumn, but is split-fertilized with application both in spring and later in the summer. The amounts of fertilizer applied are based on general Norwegian recommendations (Bioforsk, 2010b) and specific values are given in Table 12. Fertilizers are bought in Degernes (2.5 km distance) and transported with tractor to the farm.

Table 12. Fertilizers and fertilization on Farm 3.

Cereal species	Area (ha)	Fertilizer type	Amounts (kg ha^{-1})	Comments
Barley	8.6	22-3-10	540	
Oats	9.5	22-3-10	520	
Spring wheat	5.3	22-3-10	430	
		OPTI-KAS	110	Split fertilization
Autumn wheat	9.0	22-3-10	470	
		OPTI-KAS	160	Split fertilization

Liming. It is assumed that the whole farm is limed every 8 years with halfburnt dolomite (trade name “Fastline”) (417 kg ha^{-1}; 60 % CaO- eq.) from the nearest supplier (Franzefoss Miljøkalk, Rakkestad; 10 km distance). This is done by contractors and the lime is transported by tractor.

[6] Rostad, B. I., The Norwegian Agricultural Extension Service, SørØst

Pesticides. Practical spraying recommendations for the Rakkestad area include spraying against weeds and fungi and occasionally against insects as well as spraying with growth regulators. The spraying programme and active agents are shown in Table 13 (based on pers. com. Abrahamsen[7] and Rostad[8]). Pesticides are bought in Degernes (2.5 km distance) and transported by car.

Table 13. General spraying recommendations on a Farm 3 on the marine clays in southeast Norway.

	Reason for use	Trade name	Active agent	Applied dosage
All fields	Couch gras[3]	Roundup	Glyphosate	2.8 kg ha^{-1}
	Fungi on seeds	Celest FormulaM	Fludioxonil	10 g ha^{-1}
Barley				
1st spray	Weeds[1]	Tomahawk Express	Fluroxypyr Tribenuronmethyl	70 g ha^{-1} 13 g ha^{-1}
	Insects[5]	Fastac 50	Alpha-Ceypermethrin	17 g ha^{-1}
2nd spray	Fungi[2]	Delaro	Prothicoconazol/Trifloxystrobin	87.5 g ha^{-1}/75 g ha^{-1}
	Growth regulator[4]	Moddus 250 EC	Trinexapacethyl	37 g ha^{-1}
Oats				
1st spray	Weeds[1]	Tomahawk Express	Fluroxypyr Tribenuronmethyl	70 g ha^{-1} 13 g ha^{-1}
	Insects[5]	Fastac 50	Alpha-Ceypermethrin	17 g ha^{-1}
2nd spray	Growth regulator[2]	Cycocel 750	Chlormequat chloride	750 g ha^{-1}
Spring wheat				
1st spray	Weeds[1]	Tomahawk Express	Fluroxypyr Tribenuronmethyl	70 g ha^{-1} 13 g ha^{-1}
	Insects[5]	Fastac 50	Alpha-Ceypermethrin	17 g ha^{-1}
2nd spray	Fungi[1]	Delaro	Prothicoconazol/Trifloxystrobin	87.5 g ha^{-1}/75 g ha^{-1}
	Fungi[1]	Proline EC250	Prothioconazol	75 g ha^{-1}
	Lice [4]	Pirimor	Primicarb	50 g ha^{-1}
Autumn wheat				
1st spray	Weeds[1]	Hussar	Iodosulforon	10 g ha^{-1}
2nd spray	Fungi[1]	Delaro	Prothioconazol/Trifloxystrobin	87.5 g ha^{-1}/75 g ha^{-1}
	Fungi[1]	Proline EC250	Prothioconazol	75 g ha^{-1}

[1]Annually, [2]every 2nd year , [3]every 3rd year, [4]every 4th year, [5]every 5th.

[7] Abrahamsen, U., Norwegian Institute for Agricultural and Environmental Research

[8] Rostad, B.I, The Norwegian Agricultural Extension Service, SørØst

5.2.3 Diesel consumption

The annual energy requirement for processes needed for preparation of the seed bed is shown in Table 14. The 90 kW tractor is used for ploughing and levelling. The 60 kW tractor is used for combined sowing and fertilization, split fertilization and spraying. Drumming is made with a 45 kW tractor.

Table 14. Labour and diesel requirement needed for the field work on Farm 3.

Process	**Tractor (kW)**	**Workload ($ltr\ h^{-1}\ kW^{-1}$)**	**Labour ($hr\ h^{-1}$)**	**Diesel ($ltr\ h^{-1}$)**
Chemical fallow[1]	60	0.12	0.74	2.0
Ploughing	90	0.19	1.24	24.8
Levelling	90	0.19	0.45	7.7
Stone picking	90	0.19	0.2[2]	2.2
Harrowing	90	0.19	0.41	7.0
Liming[3]	120	0.19	0.29	6.6
Sowing and fertilization	60	0.12	0.78	5.6
Split fertilization[4]	60	0.12	0.23	1.7
Spraying[5]	60	0.12	0.28	2.0
Drumming	45	0.12	0.44	2.4
Treshing barley	95	0.19	0.82	14.8
Treshing oats	95	0.19	0.88	15.9
Treshing s. wheat	95	0.19	0.79	14.3
Treshing w. wheat	95	0.19	1.00	18.1

[1]Every 3rd year, [2]Value set, [3]Every 8th year, [4]per ha split fertilized, [5] per spraying.

5.3 Inventory of Farm 4, high yield

The selected farm in this area covers 237 ha and the soils vary considerably, from morainic loams to quite heavy marine clays. The soils contain a somewhat higher than normal contents of plant available phosphorus and potassium (P-AL: 9, K-AL: 25).

5.3.1 Infrastucture

Buildings and field arrondation. All grains are rinsed and dried on the farm, which requires an effective handling. A special house for this (500 m^2; for 920 m^3 grains) is found on the farm, equipped with two 18 kW fans and two 5.5 kW fans. Heat is provided through the burning of wood-chops (120000 kWh per year)**.** Additionally, there is a 150 m^2 dryer on the farm with one 18 kW fan. Burning of wood-chops is a rather uncommon heat source, and in this study we have assumed that electricity only was used for heat. There is also a shed (640 m^2) for the machinery. Expected lifetime of the buildings is 30 years.

The 26 fields (mean field size: 9.1 ha) are located both around the farm quite far away. The mean “on farm” transportation distance is approximately 10 km.

Machinery and mechanization. The machinery and equipment needed on Farm 2 are listed in Table 15.

Table 15. Machinery and equipment on Farm 4.

Machinery and equipment	"Size"	Weight (kg)	Expected lifetime (years)
Fendt 714	110 kW	7500	15
Fendt 716	118 kW	7500	15
Valtra N101	81 kW	4800	15
Thresher 22 feet	258 kW	15000	15
Harrow	5.7 m	6000	20
Loader		500	12
Stone rake	3 m	500	12
Seed drill (Horsch Pronto)	6 m	7500	10
Roller	7.6 m	3500	20
Sprayer	24 m	3000	12
Disc spreader	24 m	1000	10
Trailer1		6000	15
Trailer2		5000	15

5.3.2 Management

The fields are not ploughed. Rather, they are harrowed immediately after treshing. In order to cope with the stubble, the grain is treshed very low (short stubble), and effort is made in cutting the straw very fine. In spring, fields are harrowed once more and stone picking is done simultaneously. Stones are also picked at drumming (manually). Sowing is made with a combined sower and followed by drumming, first spraying (against weeds and insects), split fertilization (with 25-3-6), second spraying (against fungi and for growth regulation), threshing and spraying against couch in autumn after harvest.

All the grain is dried down to 15 % water content on the grain dryer on the farm. Water contents at harvesting are 18 % for barley, 20 % for spring wheat and 21 % for the winter wheat.

Crop rotation. The crop sequence varies somewhat between fields. The desired rotation starts with oilseed rape followed by winter wheat. Thereafter comes barley, spring wheat, beans, spring wheat, barley and winter wheat. Barley is grown on approximately 24 % of the farm, spring wheat on 17 % and winter wheat on 34 %. Oilseed rape is grown on approximately 17 % and beans on 8 %.

Grain yields and cereal varieties. The grain yields were quite high. Barley yields (variety Edel) were 6000 kg ha^{-1}, spring wheat yields (variety Zebra) were 6200 kg ha^{-1} and winter wheat (variety Elvis) yields were 6800 kg ha^{-1}. Seed for the coming season is withdrawn from the yield and treated with fungicides during winter.

Fertilizers. The grains are split-fertilized with application both in spring and later in the summer. The amounts of fertilizers applied are given in Table 16. Fertilizers are bought at Kambo (30 km distance) and transported with a trailer to the farm.

Table 16. Fertilizers and fertilization on Farm 4.

Cereal species	Area (ha)	Fertilizer type	Amounts (kg ha^{-1})	Comments
Barley	57	22-3-10	370	
		25-2-6	224	Split fertilization
Spring wheat	40	22-3-10	370	
		25-2-6	285	Split fertilization
Winter wheat	80	22-3-10	370	
		25-2-6	407	Split fertilization

Liming. Liming is done every 6 years with halfburnt dolomite (415 kg ha^{-1}; 60 % CaO- eq.). This is done by contractors (with a truck) and the lime is transported from the nearest supplier (Rakkestad; 60 km distance) by trailer.

Pesticides. Spraying is performed against weeds, fungi and insects as well as spraying with growth regulators. The spraying programme and active agents are shown in Table 17. Pesticides are bought in Skiptvedt (45 km distance) and transported by car.

Table 17. Spraying practices on Farm 4.

	Reason for use	Trade name	Active agent	Applied dosage
All fields	Couch gras[1]	Glyfonova Pluss	Glyphosate	540 g ha^{-1}
	Fungi on seeds[2]	Celest FormulaM	Fludioxonil	7.5 g ha^{-1}
	Wild oats[3]	Axial 050EC	Pinoxaden	40 g ha^{-1}
Barley				
1st spray	Weeds[1]	Starane XL	Fluroxipyr/florasulam	120 g ha^{-1}/3 g ha^{-1}
2nd spray	Fungi[1]	Proline EC250	Prothicokonazol	150 g ha^{-1}
	Growth regulator[4]	Cerone	Etephone	140 g ha^{-1}
Spring and autumn wheat				
1st spray	Weeds[1]	Hussar OD+ Optica mecoprop	Iodosulforon/Mekoprop-p	7 g ha^{-1}/900 g ha^{-1}
2nd spray	Growth regulator[5]	Cycocel 750	Chlormequat chloride	225 g ha^{-1} in spring wheat, 750 g ha^{-1} in winter wheat
3rd spray	Fungi[1]	Delaro SC325	Prothioconazol/Trifloxystrobin	87.5 g ha^{-1}/ 75 g ha^{-1}
		+ Proline EC250	Prothioconazol	50.2 g ha^{-1}

[1]Anually, [2]appr. 70% of the seeds are treated annually, [3]on 50% of the area every 2nd year, [4] every 2nd year, [5]every 2 out of three years.

5.3.3 Diesel consumption

The diesel requirement for the field work processes is calculated as described above and is shown in Table 18. Both the 110 kW and the 118 kW tractors are used for all operations on the farm. For simplicity, we have considered a mean tractor size of 114 kW.

Table 18. Labour and diesel requirement needed for the field work processes on Farm 4.

Process	**Tractor (kW)**	**Workload ($ltr\ h^{-1}\ kW^{-1}$)**	**Labour ($h\ ha^{-1}$)**	**Diesel ($ltr\ ha^{-1}$)**
Chemical fallow	114	0.12	0.15	2.0
Autumn harrowing	114	0.19	0.21	4.5
Spring harrowing	114	0.19	0.21	4.5
Liming[2]	140	0.12	0.13	2.2
Sowing and fertilization	114		0.40	7.5[3]
Split fertilization	114	0.15	0.12	1.3
Spraying[4]	114	0.12	0.15	2.0
Drumming	114	0.12	0.20	2.7
Treshing	Barley			14[5]
Treshing	Spring wheat			14.5[3]
Treshing	Winter wheat			20.0[3]

[1]Value set, [2]Every 6th year, [3]set in accordance with farmers estimate [4]per spraying, [5]assumed.

6. INVENTORY OF TWO FARMS IN CENTRAL NORWAY

6.1 Area description

Three major grain-producing locations are found along the Trondheimsfjord, namely the Verdal area, the Stjørdal area and the Trondheim area (seen from north to south). These locations constitute the most important grain-producing part of mid-Norway with medium sized farms most commonly located on marine clay deposits over metamorphous Ordovician rocks. We assumed that the soil was a Typic Cryaquept (USDA) – a marine clay soil with approximately 30 % clay and 4 % organic matter. Farms in the region are mainly found close by the Trondheimsfjord, which constitutes the final recipient in this area. The climate is coastal with a mean annual precipitation of approximately 800 mm and a mean annual temperature of 4.8 °C, and 11.5 °C in the growing season May – September.

6.2 Inventory of Farm 5, average yield

The selected farm is located in Inderøya community. It covers 28.3 ha (slightly larger than average) and produced barley on 24.8 ha (88 %) and autumn wheat on 3.5 ha (12 %) in 2008 (oat was thus not included, although it is not unlikely that oat would be grown on this farm some years).We assumed that the soil of the selected farm was a Typic Cryaquept (USDA) – a marine clay soil with approximately 30 % and contents of plant available phosphorus and potassium as normally found in this area (P-AL=10-12, K-AL=10-15 and K-HNO_3=150-250; pers. com. Forbord[9]). The selected farm (20 masl) lies 800 m from the Trondheimsfjord. The erosion risk is small - to - medium (NIJOS, 2010).

[9] Forbord, J. O., The Norwegian Agricultural Extension Service, Nord-Trøndelag

6.2.1 Infrastucture

Buildings and field arrondation. Room for drying of grains (200 m^2) is included as is also a shed (300 m^2) for the machinery. Expected lifetime of farm buildings were set to 30 years, which is commonly used elsewhere.

The farm buildings are located roughly in the middle of the farm, between the five fields. Field sizes are 3.6, 5.7, 2.9, 13.2 and 2.9 ha (mean 5.66 ha) and the average transport distance on the farm was 0.5 km.

Machinery and mechanization. The machinery and equipment needed are listed in Table 19.

Table 19. Machinery and equipment needed on Farm 5 in the northern Trondheimsfjord area in mid-Norway

Machinery	"Size"	Weight (kg)	Expected lifetime (years)
New tractor	90 kW	5300	15
Old tractor	60 kW	4800	15
Very old tractor	45 kW	3800	15
Thresher 12 feet	95 kW 12 feet	7000	15
Equipment			
Reversible plough	4-furrow	1360	12
Leveller	4 m	1400	20
Harrow	4 m	1200	20
Loader		350	12
Stone rake	3 m	350	12
Seed drill	3 m	2700	10
Roller	4 m	1700	20
Sprayer	12 m	200	12
Disc spreader	10 m	200	10
Trailer, rough		2000	15

6.2.2 Management

In the selected area, the fields are most commonly ploughed in autumn (90 % of the total areal) and the rest in early spring (pers. com. Forbord[1]). After ploughing follows levelling and simultaneous stone picking, harrowing and a combined sowing and fertilization, drumming, first spraying against weeds (annually) and insects (every fourth year), split fertilization with OPTI-KAS (in autumn wheat), second spraying against fungi (annually) and for growth regulation (every second year), threshing and spraying against couch grass in autumn after harvest (every third year).

In autumn, spring barley is treshed before autumn wheat. We assume that 70 % of the barley is transported directly to the nearest mill (in Steinkjer, 15 km distance). The remaining barley and all autumn wheat is transported to the grain dryer, were it gets dried down to 15 % water content and stored. Water content at treshing was assumed to be 19 % for spring barley and 18 % for autumn wheat. When prices are favourable (in late winter) the stored barley is delivered to the mill.

Crop rotation. On a cereal farm with 88 % barley and 12 % wheat, barley is presumably grown year after year on poorer fields, whereas different rotations including wheat and barley is grown on the best fields.

Grain yields and cereal varieties. The grain yields in the Trondheimsfjord area vary between cereal species and varieties, regions, farms and years. We chose to use the 10-year average yields (1998-2007) for all farms in the Inderøya community, reported by Statistics Norway (www.ssb.no). All yields are reported with a standard moisture content of 15 %. Average barley yield for the period was 3420 kg ha^{-1}, with a minimum of 2790 and a maximum of 4170 kg ha^{-1}. The corresponding value for wheat was 4390 kg ha^{-1} (2480-6520 kg ha^{-1}). The energy content of the grain was set to 18.2 and 18.3 MJ kg DM^{-1} in barley and wheat, respectively, based on the official Norwegian fodder nutrient table (Anonymous, 2009).

The cereal varieties were chosen on the basis of what is recommended for this area (pers. com. Forbord[10]). For barley we chose the variety “Tyra” (seeding rate 200 kg per ha). For autumn wheat we chose the variety “Bjørke” (seeding rate 210 kg per ha). Seeds are transported from Steinkjer (15 km distance) by truck.

[10] Forbord, J.O., The Norwegian Agricultural Extension Service, Nord-Trøndelag

Fertilizers. Fertilization in barley is considered done simultaneously with sowing in spring on the present farm (although split fertilization in barley is becoming increasingly important in the area). Autumn wheat is not fertilized at sowing in autumn, but is split-fertilized with application both in spring and later in the summer. The amounts of fertilizer applied are based on general Norwegian recommendations (Bioforsk, 2010a) and specific values are given in Table 20. Fertilizers are bought in Steinkjer (15 km distance) and transported with tractor to the farm.

Table 20. Fertilizers and fertilization on Farm 5.

Cereal species	Area (ha)	Fertilizer type	Amounts (kg ha^{-1})	Comments
Spring barley	24.8	22-3-10	440	
Autumn wheat	3.5	22-3-10	400	
		OPTI-KAS	140	Split fertilization

Liming. It is assumed that the whole farm is limed every 8 years with coarse limestone (454 kg ha^{-1}; 55 % CaO- eq.) from the nearest supplier (Verdalskalk, Tromsdalen; 15 km distance). This is done by contractors and the lime is transported to the farm by tractor.

Pesticides. Practical spraying recommendations for the Inderøya area include spaying against weeds and fungi, and occasionally spraying against insects as well as application of growth regulators. The spraying programme and active agents are shown in Table 21 (based on pers. com. Abrahamsen[11] and Forbord[12]). Pesticides are bought in Steinkjer (15 km distance) and transported by car.

[11] Abrahamsen, U., Norwegian Institute for Agricultural and Environmental Research

[12] Forbord, J.O., The Norwegian Agricultural Extension Service, Nord-Trøndelag

Table 21. General spraying recommendations on a cereal Farm 5 in Nord-Trøndelag in mid-Norway.

	Reason for use	Trade name	Active agent	Applied dosage
All fields	Couch gras[3]	Roundup	Glyphosate	2.8 $kgha^{-1}$
	Fungi on seeds	Celest FormulaM	Fludioxonil	10 g ha^{-1}
Barley				
1st spray	Weeds[1]	Starane XL	Fluroxypyr/Florasulam	70 g ha^{-1}/1.7 g ha^{-1}
	Insects[4]	Fastac 50	Alpha-Ceypermethrin	17 g ha^{-1}
2nd spray	Fungi[1]	Delaro	Prothicoconazol/Trifloxystrobin	87.5 g ha^{-1}/75 g ha^{-1}
	Growth regulator[2]	Moddus 250 EC	Trinexapacethyl	37 g ha^{-1}
Autumn wheat				
1st spray	Weeds[1]	Starane XL	Fluroxypyr/Florasulam	70 g ha^{-1}/1.7 g ha^{-1}
2nd spray	Fungi[1]	Delaro	Prothioconazol/Trifloxystrobin	87,5 g ha^{-1}/75 g ha^{-1}
	Fungi[1]	Proline EC250	Prothioconazol	75 g ha^{-1}

[1]Annually, [2]every 2nd year , [3]every 3rd year, [4]every 4th year.

6.2.3 Diesel consumption

The diesel requirement for the field work processes is calculated as described above and is shown in Table 22. The 90 kW tractor is used for ploughing, levelling and the combined sowing and fertilization. Most other operations are done with the 60 kW tractor but drumming is done with the 45 kW tractor. We assume that treshing is done with a 4 m tresher (95 kW; 0.19 ltr diesel per kW motor effect).

Table 22. Labour and diesel requirement needed for the field work processes on Farm 5.

Process	Tractor (kW)	Workload (ltr h^{-1} kW^{-1})	Labour (h ha^{-1})	Diesel (ltr ha^{-1})
Chemical fallow[1]	60	0.12	0.74	2.0
Ploughing	90	0.25	1.24	27.9
Levelling	90	0.19	0.45	7.7
Stone picking	90	0.19	0.2[2]	2.2
Harrowing	90	0.19	0.41	7.0
Liming[3]	120	0.19	0.29	6.6
Sowing and fertilization, barley	90	0.12	0,90	6,5
Sowing, wheat	60	0.12	0.76	5.5
Spring fertilization	60	0.12	0.30	2.2
Split fertilization	60	0.12	0.23	1.7
Spraying[4]	60	0.12	0.28	2.0
Drumming	45	0.12	0.44	2.4
Treshing, barley	95	0.19	0.72	13.0
Treshing, w. wheat	95	0.19	0.87	15.7

[1]Every 3rd year, [2]value set, [3]every 8th year, [4]per spraying.

6.3 Inventory of Farm 6, high yield

The selected high-yielding farm in this area has an acerage of 98 ha, where barley is grown on approximately 80 % of the farm, oats on 10 % and winter wheat on 10 %.

The soils of the selected farm varies considerably, from morrainic loams (on 60 % of the area) to quite heavy marine clays (on 40 % of the area). The soils contain approximately 4 % organic matter, and have a somewhat higher than normal contents of plant available phosphorus and potassium (P-AL: 8-10, K-AL: 10).

The erosion risk varies from small-medium (70 %) to high (appr. 30 %) (NIJOS, 2010).

6.3.1 Infrastucture

Buildings and field arrondation. All grains are delivered directly to the mill and no room for drying grains exists. Approximately 20 % is delivered with tractor at a local mill 0.5 km distance and 80 % is transported with trailers to Trondheim. There is a shed (500 m^2) for the machinery. Expected lifetime is 30 years.

The 22 fields (mean field size 4.5 ha) are located both around the farm quite far away. The mean "on-farm" transportation distance is approximately 4 km.

Machinery and mechanization. The machinery and equipment needed on Farm 3 are listed in Table 23.

Table 23. Machinery and equipment on Farm 6.

Machinery and equipment	"Size"	Weight (kg)	Expected lifetime (yr)
John Deere	110 kW	6000	15
New Holland 7740	70 kW	5000	15
Massey Ferguson 2045 Tresher	110 kW, 12 feet	6500	15
Reversible plough	4-furrow	1350	12
Reversible plough	3-furrow	1100	12
Cross-kill harrow[1]	4.5 m	6000	20
Loader		500	12
Stone rake	3 m	500	12
Kongskilde Seed drill	3 m	2000	10
Hardy Sprayer	15 m, 1200ltr	1000	12
Bøgballe disc spreader	12 m	600	10
Trailer		5000	15

[1] The cross-kill harrow is also used for drumming.

6.3.2 Management

The fields are ploughed in spring. Thereafter they are treated with a cross-kill harrow and stones picked before the fields are sowed with a combined sower. Drumming is only performed on fields with much stone on the surface (approximately 20 ha yearly) then follows first spraying (against weeds), split fertilization (in winter wheat), second spraying (against insects and fungi and for growth regulation), threshing and spraying against couch in autumn after harvest (on 20 ha yearly).

All the grain is delivered directly to the mill. Water contents at harvesting are 21 % for barley, 17 % for oat and 21 % for the winter wheat.

Crop rotation. The crop sequence is basically barley after barley.

Grain yields and cereal varieties. The grain yields reasonably high for the area. Barley yields (variety “Helium”) were 5000 kg ha^{-1}, oat yields (variety “Gere”) were 4500 kg ha^{-1} and winter wheat (variety “Bjarne”) yields were 5200 kg ha^{-1}.

Fertilizers. The barley and oat is only fertilized in spring, along with a special start-fertilizer (40 kg Optistart ha^{-1}) while winter wheat is split-fertilized with application both at sowing in autumn, in spring and later in the summer. The amounts of fertilizers applied are given in Table 24. Fertilizers are bought in Verdal (35 km distance) and transported with a trailer to the farm.

Table 24. Fertilizers and fertilization on Farm 6.

Cereal species	Area (ha)	Fertilizer type	Amounts (kg ha^{-1})	Comments
Barley	78	12-23-0	40	Opti-start
		22-3-10	560	
Oat	10	12-23-0	40	Opti-start
		22-3-10	510	
Winter wheat	10	22-3-10	100	At sowing
		22-3-10	400	In spring
		16-0-0	250	Split fertilization

Liming. Liming is done every 10 years with coarse limestone (400 kg ha^{-1}; 55 % CaO- eq.). This is done by contractors (with a tractor) and the lime is transported from the nearest supplier (Verdalskalk, Tromsdalen; 60 km distance) by trailer.

Pesticides. Spraying is performed against weeds, fungi and insects as well as spraying with growth regulators. The spraying programme and active agents are shown in Table 25. Pesticides are bought in Stjørdal (15 km distance) and transported by car.

Table 25. Spraying practices on Farm 6.

	Reason for use	Trade name	Active agent	Applied dosage
All fields	Couch gras[1]	Glyfonova Pluss	Glyphosate	1080 g ha^{-1}
	Fungi on seeds[2]	Celest FormulaM	Fludioxonil	7.5 g ha^{-1}
	Wild oats[3]	Puma	Phenoxaprop-P-ethyl	69 g ha^{-1}
Barley				
1st spray	Weeds	Granstar Power	Tribenuron methyl	8 g ha^{-1}
			+Mecoprop	587 g ha^{-1}
	Sopp	Stereo 312.5 EC	Cyprodinil	175 g ha^{-1}
			+Propiconazol	44 g ha^{-1}
2nd spray	Insects	Fastac 50	Alpha-Cypermetrin	7.5 g ha^{-1}
	Fungi	Delaro SC 325	Prothiconazol	87.5 g ha^{-1}
			+Trifloxystrobin	75 g ha^{-1}
	Growth regulator[4]	Cerone	Etephone	120 g ha^{-1}
Oats				
	Weeds	Granstar Power	Tribenuron methyl	8 g ha^{-1}
			+Mecoprop	587 g ha^{-1}
	Growth regulator	Modus 250 EC	Trinexapac-ethyl	50 g ha^{-1}
Winter wheat				
1st spray	Weeds	Granstar Power	Tribenuron methyl	8 g ha^{-1}
			+Mecoprop	587 g ha^{-1}
	Fungi	Stereo 312.5 EC	Cyprodinil	175 g ha^{-1}
			+Propiconazol	44 g ha^{-1}
2nd spray	Fungi	Proline	Propiconazol	150 g ha^{-1}

[1]20ha pr year (=appr. 20% of the farm), [2]appr. 70% of the seeds are treated annually, [3]on 15ha each year, [4]on 50% of the area sown with barley.

6.3.3 Diesel consumption

The diesel requirement for the field work processes is calculated as described for Farm 1 (above) and is shown in Table 26. Both the 110 kW and the 70 kW tractors are used for all operations on the farm. For simplicity, we have considered a mean tractor size of 90 kW, an exception being the harrowing, which is performed with the largest tractor.

Table 26. Labour and diesel requirement needed for the field work processes on Farm 6.

Process	Tractor (kW)	Workload (ltr h^{-1} kW^{-1})	Labour (h ha^{-1})	Diesel (ltr ha^{-1})
Chemical fallow[1]	90	0.12	0.26	2.8
Ploughing	90	0.19	1.735	29.7
Spring harrowing	110	0.19	0.39	8.2
Liming[2]	140	0.12	0.13	2.2
Sowing and fertilization	90	0,12	0.90	9.7
Split fertilization	90	0.12	0.34	3.7
Spraying[3]	90	0.12	0.26	2.8
Treshing barley	110	0.19	1.15	24
Treshing oat[4]	110	0.19	1.19	24.9
Treshing w. wheat	110	0.19	1.19	24.9

[1]on 20% of the farm annually, [2]Made by contractor every 10th year, [3]per spraying, [4]assumed equal with winter wheat.

7. Data selection and quality assessment

The data discussed below are those gathered during farm inventory. Background information on the calculation of environmental impact is discussed initially in this report.

The farms with average yields are real farms in the sense that they can physically be found on a map. We used the actual crop distribution on these farms as it was in 2008. All activity on the farm (management), along with details on machinery, mechanization and diesel consumption was, however, generalized in order to create a typical farm representing the respective region. Such information was mainly provided by local agricultural advisors (The Norwegian Agricultural Extension Service), which possess considerable experience and an intimate, local knowledge on questions related to grain production.

The farms with high yields are real farms in all respects. Information regarding these farms were given by the farmers themselves through interviews, and the information is regarded as highly trustworthy.

On Farm 2 and 4 other crops than cereals were included in the rotation. We have provided some information on this matter, but we have not made any thorough inventory of these crops. Including other crops than cereals in the crop rotation, may have contributed to the higher cereal yields of these farms.

7.1 Infrastructure

Farm infrastructure is described briefly. Many Norwegian farms are, of different reasons, heavily mechanized. The number of tractors might be higher than we have reported. Moreover, much old equipment and machinery can be found behind the barn. We have reported only what is considered necessary for the production of grains on a farm like this. It should be mentioned here that machinery being older than the expected lifetime, will, contribute to the emissions thorough the use of diesel and lubrication only.

7.2 Management

Management practice was not diverging very much between the inventoried cereal farms, reflecting a fair bit of similarity in terms of soil conditions and farm size between the climatically different regions.

Coming to grain yields, we chose to use the 10-year mean yields (1998-2007), reported by Statistics Norway (www.ssb.no) on farms with average yields. We consider this a good choise since it eliminates the annual variation.

The amount of fertilizers assumed applied on the average yielding farms was calculated from general Norwegian recommendations (Bioforsk, 2010a), and the amounts of pesticides were given by local advisors. It could be argued that some farmers tend to use somewhat more fertilizer and pesticides than that recommended. We do, however, not have any robust data available on the actual use of these inputs on the farms.

7.3 Diesel consumption

Robust data on diesel requirement for the field work is difficult to find for the specific conditions given. We have therefore calculated the diesel useage. This was made in a stepwise fashion. We first used the "Drift" model (Nielsen and Sørensen, 2010) to find the number of man hours needed to perform the various operations, and then we calculated the diesel needed per hour by using conversion factors. In general, the calculated diesel consumption rates were highly comparable to literature values (see below), and to the data given by the farmers on the high yielding farms. Moreover the total amount of diesel calculated for the farms coincided nicely with values obtained by economical studies of Norwegian cereal farms with comparable size (NILF, 2010).

Ploughing is the most time- and energy-consuming operation related to preparation of the seed bed and is also blurred with the largest variation in energy use per hectare. The reason for this variation is the deep soil penetration with the plough, making variability in soil properties very dominant. Literature values from Scandinavia vary from 15 ltr ha^{-1} (Flysjø et al., 2008) and 16 ltr ha^{-1} (general value on a general soil, 16 cm ploughing depth; Dalgaard et al., 2002) to 23 ltr ha^{-1} on a clay soil (Johansson, 1998). In Norway, Stabbetorp (2010) measured 15 ltr ha^{-1} when ploughing a silty soil. Through our stepwise calculation, we found somewhat higher values than this, ranging from 21.2 (Farm 1) to 29.7 ltr ha^{-1} on Farm 6.

We assumed that levelling required approximately the same diesel consumption as needed for stubble harrowing and used the latter operation as input in the model. This gave an estimated labour of 0.34 – 0.45 h ha^{-1} and a diesel consumption of 7.7-8.7 ltr diesel ha^{-1}. In comparison, the farmer on Farm 2 considered that he used approximately 0.5 hr of labour per ha for the combined operation levelling + stone picking.

Liming is considered done by contractors and we have in accordance with this assumed the use of quite large tractors. The diesel consumption was calculated to 0.4-0.8 ltr ha^{-1} yr^{-1}. In comparison, Dalgaard et al. (2002) assumed that liming required 1.5 ltr ha^{-1} yr^{-1}.

Sowing and fertilization is in most cases done simultaneously. We calculated a labour between 0.4-0.9 hr ha^{-1}, leading to a diesel requirement of 5.6-9.7 ltr ha^{-1}. The farmer on Farm 2 considered that he needed similar amount of labour (8-9 h 15 ha^{-1}), loading included. Approximately equal values (8 – 10 ltr ha^{-1}) are also given by Flysjö et al. (2008). A measured value of 6 ltr ha^{-1} is reported under Norwegian conditions by Stabbetorp (2010). The farmer on Farm 4 considered, however, the driving speed to be 10-12 km h^{-1} and that somewhat more than 4 ha could be sowed and fertilized per hour. This is only half the labour considered necessary on Farm 1 and as calculated from the Drift model (0.4 hr ha^{-1}) as well.

Split fertilization is commonly done with disc spreaders in Norway. Our calculations gave an appreciably lower value 1.3-3.7 ltr ha^{-1} than given for fertilization (4 ltr ha^{-1}) by Flysjö et al. (2008).

Spraying requires between1.5-2 ltr ha^{-1} for each spraying. This is in agreement with values given by Flysjö et al. (2008) and measurements (1.5 ltr ha^{-1}) made by Stabbetorp (2010).

In a Swedish study, Flysjö et al. (2008) reported that 22-25 ltr diesel pr ha is needed for treshing, depending on whether the straw is chopped or not. The Swedish data seem reasonable, but lower figures are also found, e.g. 13.3 ltr ha^{-1} (Traktor, 2008). The latter value refers to a very large thresher, and seems unrealistic for a farm in Stange (pers. com. Endrerud[13]). Other low values are, however, reported from actual measurements in Norway.

[13] Endrerud, H.C., Hedmark University College

Treshing barley required 12 ltr diesel ha^{-1} in a field measurement while 18 ltr ha^{-1} was needed for treshing of autumn wheat (Stabbetorp, 2010) The diesel consumption needed for threshing generally depends on how much material which is processed and is, therefore, dependent on the yields, type of grains and amount of straw. The Danish model "Drift" takes this into account. Oats are not dealt with in the "Drift"-model, however, so we assumed that the labour requirement was 10 % higher than that of spring wheat. Compared with literature data, the calculations presented in our work (14-24.9; on Farms 1 and 6, respectively) seem reasonable.

For every percent unit of water reduction, we considered that approximately 18.8 kWh of electric energy is needed per ton grain (taken from Edström et al., 2005). Somewhat lower energy consumption (15 kWh ton^{-1}) is reported by Sørebø og Sakshaug (2010). Being a web-site model, however, the latter has not been peer-reviewed.

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