Tillers'

Tech*Guide*

Neck Yoke Design and Fit: Ideas from Dropped Hitch Point Traditions

by Richard Roosenberg

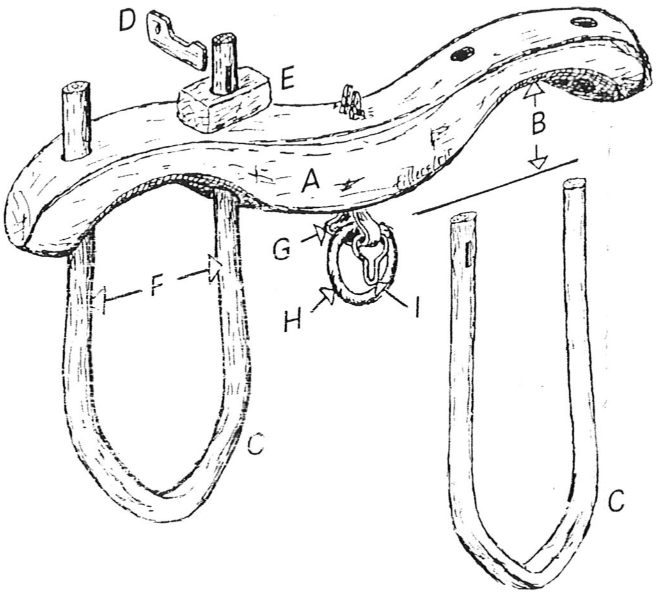

***FIGURE 1:** Traditional neck yoke design with dropped hitch point: **A**, beam; **B**, distance hitch point is lowered; **C**, bows; **D**, bow pins; **E**, shims/spacers; **F**, bow width; **G**, staple; **H**, pole ring; **I**, hook for chain*

Acknowledgement of Reviewers

This is the third draft of this TechGuide. It has benefitted from the review suggestions of several readers: Steve Belkoff, Robert J. Boynton, Jr., William Bunting, Drew Conroy, Marcia Keith, Peter Rice, Jack Shoemaker, and Jochen Welsch. Future editions will integrate added suggestions and improvements to text and illustrations. Please send comments to:

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Introduction

To work efficiently, a team of oxen needs a yoke which fits them and the tasks at hand. The traditions of yoke making have much to offer as we search for improvements in yoke effectiveness.

I was struck by the importance of yoke fit and design when training the first pair of oxen at Tillers. I had worked with a number of pairs in West Africa in a UN-FAO sponsored project. Tillers started with a team of 18-month-old Brown Swiss. I began training with a simple yoke like I had used in the African project. It had a pole for a beam, steel rods for bows, and a clevis extending behind the beam for hitching. After a few weeks the team pulled a stone boat willingly, but if I stepped onto it, they would stop.

Then, I placed an historic yoke on the team. They did not mind its extra weight and readily pulled the stone boat. I stepped on and they continued to pull without hesitation. A second person got on and the team still pulled. It took the weight of a third person to discourage them. I was amazed that changing the yoke permitted adding about 330 pounds (150 kg) to their load. I immediately started analyzing that old yoke and reading what I could find about traditional yoke design and dynamics. Obviously, those yokes were superior in some simple ways.

The traditional southern yokes (of Asia and Africa), as those with which I worked in the UN-FAO project in Benin used staves/bows merely to keep the

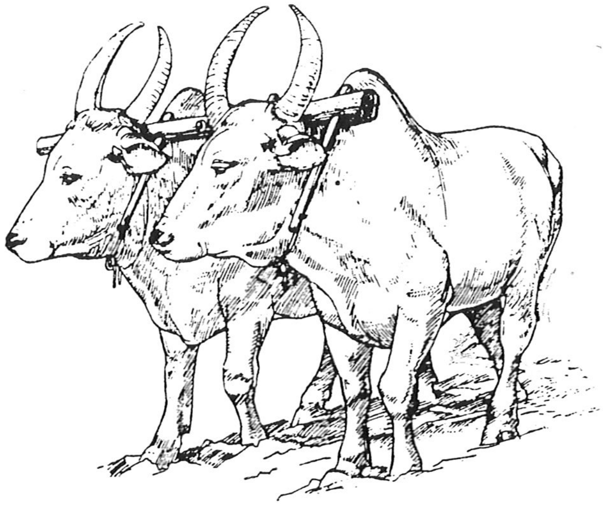

FIGURE 2:* *Many Asian and African cattle have a hump which provides a natural seat for a yoke. *(from Farm Implement for Arid & Tropical Regions, UN)*

oxen in place. The dropped hitch yoke developed over years to use the bows in several additional roles which markedly increased its effectiveness.

Capturing the advantages of the traditional yoke requires understanding its dynamics and its fit. This guide gives a brief overview of yoke dynamics, then examines fitting the yoke to specific oxen, and finally attempts to integrate a number of use and fit issues into a design process. A complex of interactions among dynamics, fit, and use makes small variations critical to attaining the functional advantages of the dropped hitch point design. This **Tech*Guide*** probes these interactions in detail. We do not want to complicate the issues; however, we are convinced that the subtleties are important. Considerable increases in power effectiveness can be gained by refining local designs. Building the yokes with these features can be accomplished with a range of materials, skills, and uses. A separate **Tech*Guide*** will describe building techniques for neck yokes with a number of successful alternative construction techniques. This guide focuses on principles which make the neck yoke work well. We hope that a better understanding of its dynamics will encourage local innovation.

Dynamics of the Dropped Hitch Point

The most important and distinctive feature of the northern neck yoke is its dropped hitch point. Rather than hitching directly behind the beam and its fulcrum, yoke makers moved the hitch point below the beam. This introduced a new mechanical dynamic. As a load is pulled from the hitch point, the hitch point moves back and rotates the beam of the yoke (see Fig. 3). The bows also rotate and press back against the shoulders. First, this increases the total contact surface of the yoke to include the back surfaces of the bows. Any increase in contact surface reduces force per unit of surface, pain, and the incidence of sores or galls. Secondly, the backward rotation of the bows counters the tendency for the beam of the yoke to slide up the necks of the oxen.

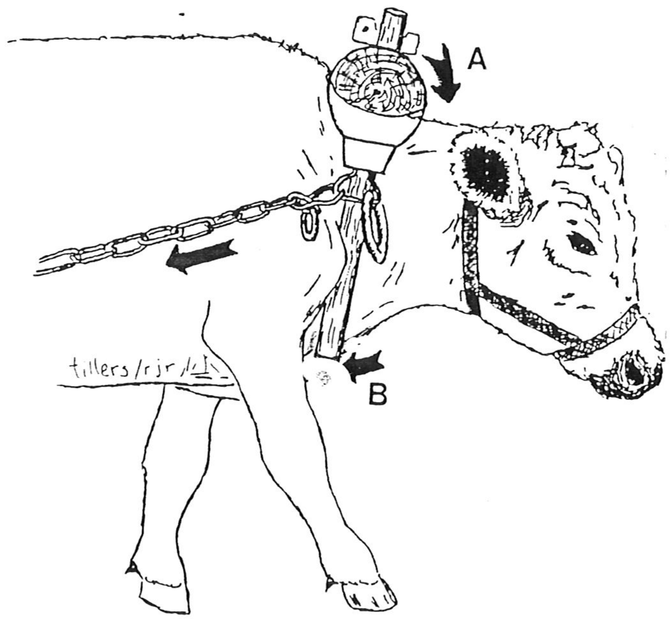

FIGURE 3:* *While the yoke used in Africa and Asia rotates the bows/staves forward, the traditional dropped hitch point neck yoke rolls them back against the shoulders. *(Roosenberg, Tillers Report, 7:1, 7)*

Since the shoulders of oxen are very mobile, the rotated bow must be kept from hitting the points of the moving shoulders (see Fig. 4). Thus, the cross bars, which tie the staves together below the neck on Indian and many southern neck yokes, would cause problems if rotated back with a dropped hitch point. Lowering the hitch point must be accompanied by appropriate bow design changes. Older ox drivers say the curve of the bent bow is very important for clearing the

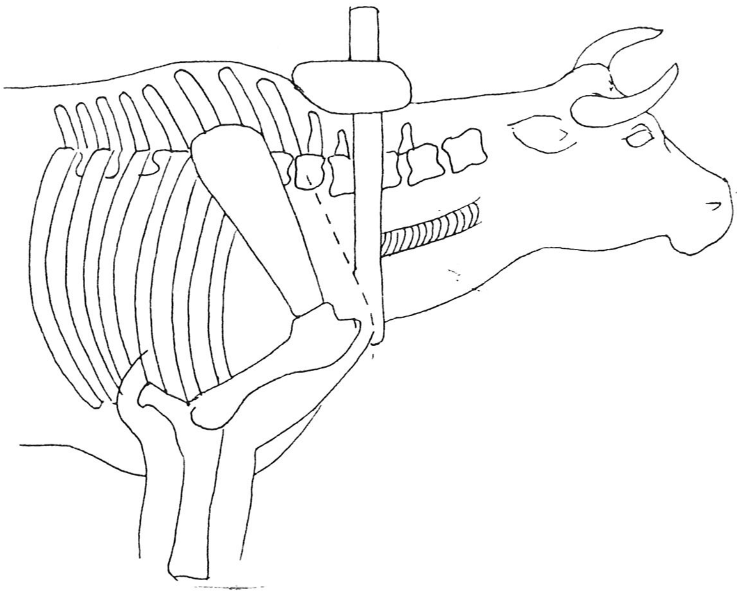

***FIGURE 4:** The bow of a dropped hitch point yoke must accommodate the anatomy of the shoulder of an ox. (Porter, Small Farmer's Journal, 9:3, 27)*

shoulder and for avoiding pain and injury. Careful observation of specific animals is essential for optimizing fit to the anatomical characteristics of an animal or a breed. The added roles that the traditional northern neck yoke places on the bows requires that they be fit much more precisely.

Fitting Bows

The first parts of the yoke to be fitted to oxen are the bows. The size of the bows is such an important factor that yokes themselves are commonly referred to by the width of their bows. For example, a pair of calves may wear a 5-inch (12.5cm) yoke and one-ton oxen may require a 12-inch (30cm) yoke. The width of a bow is measured between its vertical shafts (see Fig. 5). It is not measured from center to center of the holes in the beam of the yoke. The measurement is of the inside width of the space in which the ox can move its neck. This width is generally about 1 inch (2.5cm) wider than the neck of the ox (when measured just a few inches behind the head). This is more commonly expressed by teamsters as the neck width plus the thickness of a hand. If the oxen already have a yoke, the fit of the bows can be tested by pulling it forward without a load and attempting to insert a hand in one side between the neck and the bow (see Fig. 6). If there is only room for the tips of your fingers (0.5 inches, 1.25cm), it is time for a larger yoke. If there is room for your wrist (1.5 inches, 3.75cm), a smaller yoke should be tried.

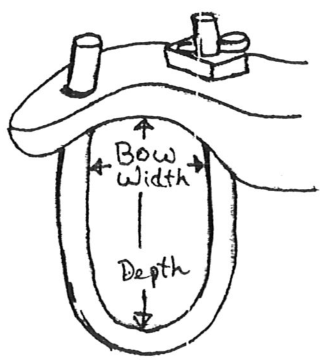

***FIGURE 5:** Bow width and depth are internal dimensions measured inside the opening.*

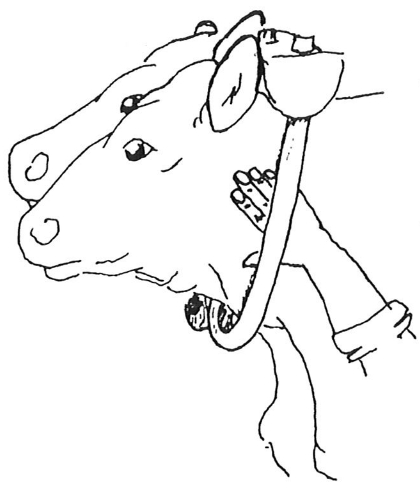

***FIGURE 6::** A snug hand between the animal's neck and the side of the bow with the yoke forward usually indicates a good bow width. (Drawn by Marcia Keith)*

The traditional yoke with a dropped hitch was fitted to the animal more closely and precisely than yokes in Asia and Africa. The farmers of the tropics worked with humped Zebu or Brahmin cattle which have a natural seat for the yoke (see Fig. 2). Tillers is convinced, nonetheless, that the advantages of well-fitted bows can also have significant benefit for cattle with humps.

The width of bows is critical to the pulling capacity and comfort of oxen. For harnessing their power, the greatest distinction between oxen and draft horses is the mobility of the shoulders of oxen. Watching a team of oxen from the side as they pull in

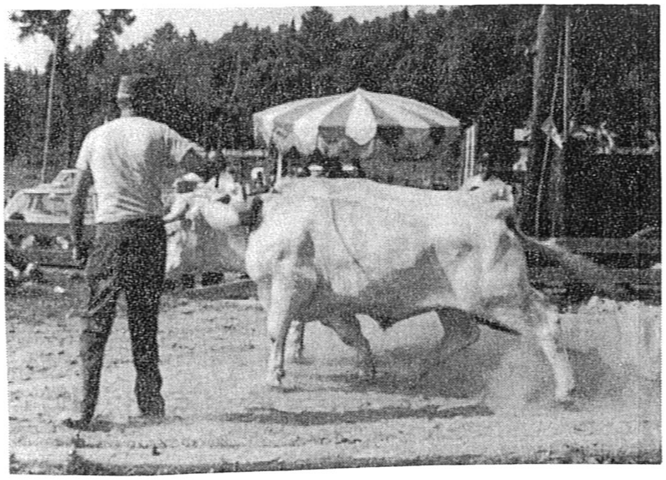

FIGURE 7: The bow of a well-fitted yoke is obscured by the shoulder as oxen step forward with a load. *(Drew Conroy, Tillers Report, 8:1, 4)*

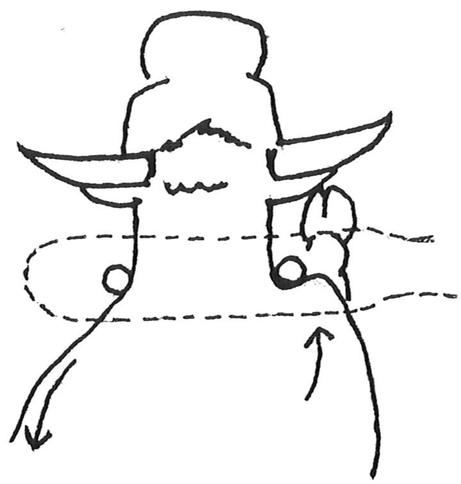

FIGURE 8: Looking down on a yoked ox, you would see the sides of the bow fit between the neck and the shoulder as the ox steps forward. *(Drawn by Marcia Keith)*

a well-fitted yoke, you can see the points of their shoulders pass outside the bows.[1] The shoulders actually obscure the bow for a moment in each step (see Fig. 7). If the bow is too wide, the shoulders will hit the sides rather than moving freely beyond them.

Regrettably, there is no recognized way of measuring the ideal spacing when under a load. If an animal is relatively wide-framed with a thin neck (for example, a working cow) testing the fit when the yoke is forward on the neck may lead to the bows being too tight when pulled back into place. Or for many mature animals, as yoke maker, Robert J. Boynton, Jr., notes, it will require more space than the thickness of a hand to allow the bows to move back to the shoulders as they should. The neck of larger animals has a wider flare approaching the shoulders. Although attentive observation is required to double check the hand test, use of the hand serves as a good starting point.

To a point,[2] the larger the diameter of the wood or tubing from which the bows are made, the more comfortable the yoke will be. A larger surface distributes draft force. However, bow stock is too thick when it is larger than the space between the neck and forward shoulder (see Fig. 8). Traditional bow stocks vary from 1.25 inches (3cm) in diameter for small animals to 2 inches (5cm) for large oxen.

The depth of the bow -- the distance from the beam to the bottom of the bow -- is also critical (see Fig. 5). This distance can and should continue to be adjusted throughout the use of a yoke. When the hole for the key or bow pin is cut in the bow, a generous amount of extra room should be left for adjustment, 1-2 inches (2.5-5cm). Spacers of 1/8th to 1 inch (3 to 25mm) thickness are shaped like washers from wood or leather. They are placed over one end of the bow and secured under the bow pin. Various combinations of thicknesses give fine adjustments in bow depth. In making these adjustments, a hand test is again used with the yoke forward and without a load. This time the hand is placed in the bottom of the bow and the loose flesh under the neck should just touch it. There should be 1 to 1.5 inches (2.5 to 3.75 cm) of space between the yoke and the flesh of the neck. This test is more subjective than the test for bow width. The amount of loose flesh seems to differ between breeds as an indicator of where the bow will contact the brisket when it swings back under a load.

If the bow is too low, it will press against the windpipe and cut off the ox's breathe. The bow is more likely to cut the animal's breathe when low than when high. The windpipe is protected better high in the neck than in the brisket (see Fig. 9). If a team becomes winded rapidly under a heavy load, experiment with additional spacers to raise the bow somewhat.[3] Drew Conroy suggests two indicators. If the oxen drop their heads in order to enjoy easier breathing, the bow is likely set too high. On the other hand, if the bow is too low, the oxen are likely to throw their heads up.

***FIGURE 9:** The windpipe is more exposed in the brisket than higher in the neck.* *(Drawn by Marcia Keith)*

Robert J. Boynton, Jr. says that dropping the bow 2 inches (5 cm) or more below the neck will cause problems as it will begin to hit the brisket when pulling a load. He says, "Most of the time you should run a tight bow. If you have a low bow, the steer cannot feel the whole bow. With a tight bow the steer will hold his head up so you can tell somewhat how the yoke will fit."

Beam Shape and Size

The thickness of the beam gives both strength and comfort. A beam that is about 2/3 the width of the bow should have plenty of strength if the wood is reasonably strong. However, for comfort the beam's thickness above the neck piece should be about 80-90 percent of the bow width. This extra width, front to back, provides a larger contact surface against which the animal's neck can push. For example, a yoke with 7.5-inch bows should have a beam of about 5 inches front to back at its center for strength but 6 to 6.75 inches over the necks.

Common Beam Stock Sizes*

Bow Width (inches)	Bow Width (cm)	Beam Thickness (inches)	Beam Thickness (cm)	Beam Depth (inches)	Beam Depth (cm)
5	12.5	4	10	6	15
6	15	5	12.5	7	17.5
7	17.5	6	15	8	20
8-10	20-25	7	17.5	9	22.5

* These are common sizes used by Robert J. Boynton, Jr.

When possible, the yoke should be taken from a tree double the thickness of the yoke. In many species of trees, especially when dried rapidly, cracks develop radially from the heart. If the heart is centered in the beam, some of those checks and cracks are likely to show-up on the contact surface. By using a tree double the thickness of the beam, you can split it through the heart, shape one or two yokes out of each half, and greatly reduce the likelihood of discarding a valuable piece of wood because cracks are causing sores.

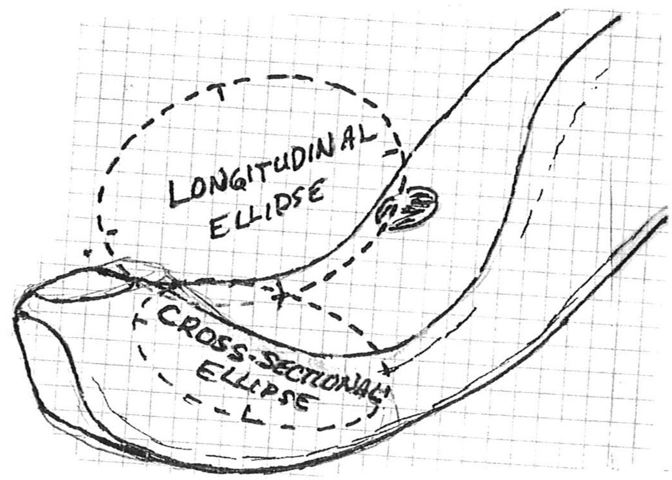

***FIGURE 10:** The neck piece can be described by two elliptical curves. The longitudinal curve is concave, and the cross-sectional curve is convex.* *(Drawn by Roosenberg)*

Shape of the Neck Piece

Two curves define the neck seat.[4] One is longitudinal and the other cross- sectional. The longitudinal curve is concave and fits across the neck just forward from the shoulders. The neck of an ox flattens as the ox lowers its head to push into a load.[5] The best fitting curve is the flattened side of an oval or an ellipse. (A good ellipse for a starting point can be described as a circle with a diameter of 1.125 times the bow width and rotated 60°.) A thinner animal may need closer to a circular curve.

The cross-sectional curve is generally simple. Most yokes are reversible front to back. With a dropped hitch point, the front edge of the beam rolls down enough to present a good working angle to the neck. A modest cross-sectional curve that is symmetrical from front to back facilitates this. (A good curve is close to an ellipse of 30°.)

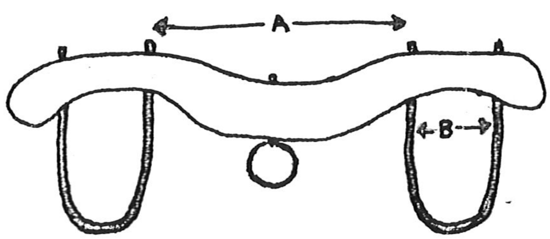

FIGURE 11:* *Between the inside bow holes,* A*, is generally 2.5 to 3 times the width of the bows,* B*. *(Drawn by Marcia Keith)*

Length of the Beam

For plowing and field use, oxen should be placed relatively close together in a yoke. The driver has better control of them when they are close and they seem to coordinate their starts better, especially with a heavy load. A rough general rule of thumb for the distance on the beam between the inside bow holes is 2.5 to 3 times the width of the bows. (Or, from center to center of the animals would be 3.5 to 4 times the width of the bows.) Thus, for a 7.5-inch yoke, the distance between the bows would be about 18.75 to 22.5 inches. Following this rule of thumb, the length of the beam stock could be rough cut to 7 times the bow size to allow some realignment for avoiding knots and for final trimming.

Rules of thumb, however, are not always satisfactory. If the team is relatively fat in the gut, they will have a hard time walking parallel to each other. If on a straight lane a team walks in a wedge pattern, "/ \", with their rear-ends wide as you would look down on them, the yoke may be too narrow. If you notice this, also watch from behind to see if their front legs angle up and outward "\ /" as if they are continuously pulling out from each other. This is an inefficient walking pattern and may be corrected with a wider yoke.[6]

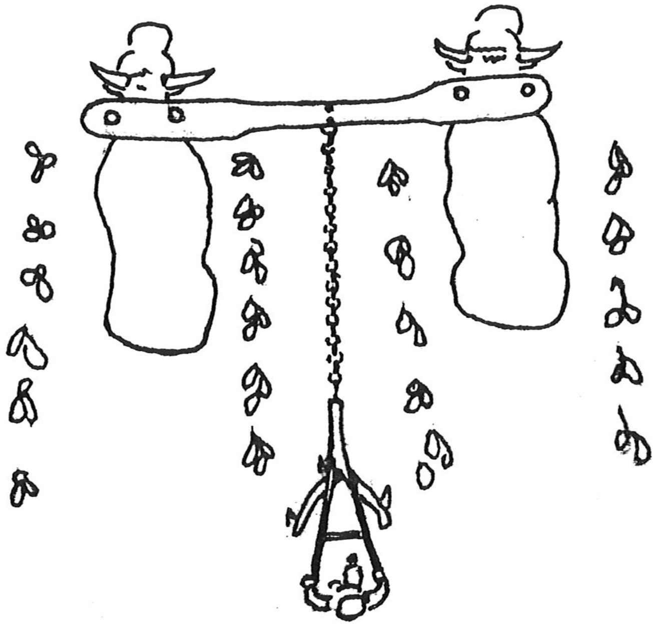

FIGURE 12:* *For between-the-row weeding with a team, the animals have to be centered between the outside rows, or 2+ times the row spacing. *(Drawn by Marcia Keith)*

The length of the beam of a yoke also depends on plans for its use. If the yoke is for weeding row crops, its length must correspond to the spacing of the rows. For a team pulling a between-the-rows weeder, this means a long beam. The team of animals must straddle the pair of rows between which the weeder is working ("**X:$_v$:X**", where X represents the animals and v the weeder). Theoretically, this means that the animals should be centered at twice the row spacing (see Fig. 12). Fewer plants will be trampled, however, if they are spaced about 10 percent further apart (when one ox moves a little ahead of the other the distance between them decreases as the angle of the yoke increases). With an over-the-row weeder the animals will straddle a single row; and thus, the yoke spacing should be one times the row spacing. With modern agronomic suggestions for closer row spacing, this may present problems for larger animals. Indeed, better crop production may result from wider than agronomically ideal row spacing, if it permits better weed control.

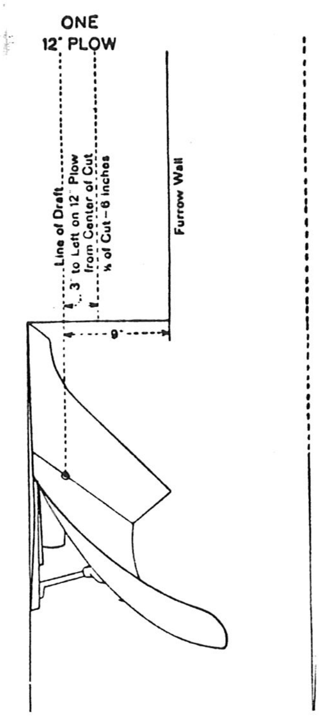

FIGURE 13: ***An overhead view showing alignment of the hitch point with the plow's center of resistance and the furrow.*** *(from John Deere's 12th edition of <u>Operation, Care and Repair of Farm Machinery</u>)*

The moldboard plow presents a yoking challenge in which the working width of the tool is very narrow, perhaps 8-12 inches (20-30cm). The point of resistance of any tool should be centered behind the yoke's hitch point, however; with one animal obliged to walk in the furrow and the tool working right next to it, there is little room to center the yoke's hitch point on the tool ("$X_v\underline{X}$" where $\underline{X}$ represents the ox in the furrow). The center of resistance of a moldboard plow is about 1/4 the width of cut from the landside, or 3/4s from the furrow (see Fig. 13). The furrow animal prefers to walk in the center of the prior furrow but can be pushed to 2/3s the width of the furrow toward the plowed ground. (Walking in the plowed ground is extremely tiring.) These factors suggest a yoke beam that centers the animals at 2[3/4 x cut + (1/2 to 2/3) x cut] or 2 1/2 to 2 5/6s times the width of cut. With a 12-inch plow that would be 30 to 34 inches between the centers of the animals. Such a narrow yoke is hard to achieve when oxen have bow sizes of more than 8 1/2 inches. While most moldboard plows can be adjusted to compensate for off-center draft, "$X\ _v\underline{X}$"; the trade-off is greater friction on the landside.

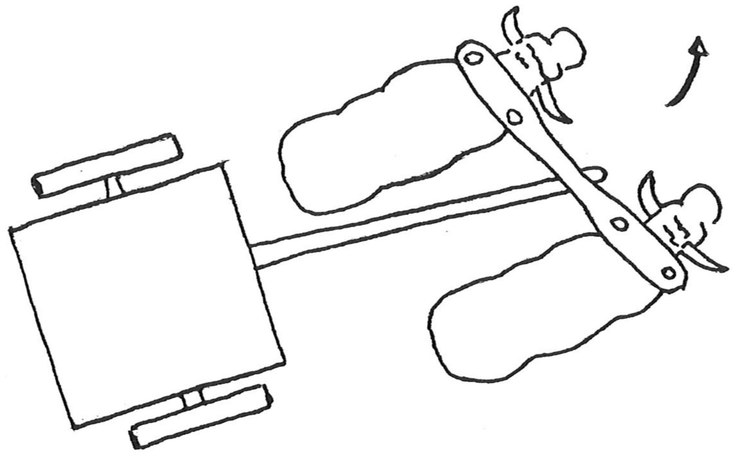

FIGURE 14:: ***When turning with a rigid tongue, the inside ox likes room to swing his rear in line with the turn.*** *(Drawn by Marcia Keith)*

The means of hitching from the yoke to the tool also affects the desirable length of beam and distance between animals. A traction chain is thin and flexible. Animals tolerate it well and learn to maneuver with it quickly. Rigid tongues, on the other hand, cause a greater obstruction to the animals' maneuvering around bends, and especially sharp turns. Oxen are generally less adept at stepping sideways than horses. They like to turn their bodies. Since their heads are fixed in place by the yoke, they swing their back ends to align their bodies for turns (see Fig. 14). Thus, when rigid tongues are used, oxen appreciate the added room provided by a longer beam. These can have a distance between the inside bow holes of 4 to 5 times the bow width. Pulling a cart with a longer beam usually causes few problems (other than requiring an extra yoke in addition to the one for plowing).

For tasks such as working circular animal-driven gear powers, oxen use a traction chain but, nonetheless, are constantly turning and need more space between each other than they ordinarily would. Also, the yoke should be designed to compensate for the extra distance that the outside ox must walk. To accomplish this, the yoke's hitch point can be placed off-center (see Fig. 15). A greater distance from the staple, or hitch-point, to the outside ox will give it added leverage and reduce its draft to compensate for the greater distance it must walk. For example, with

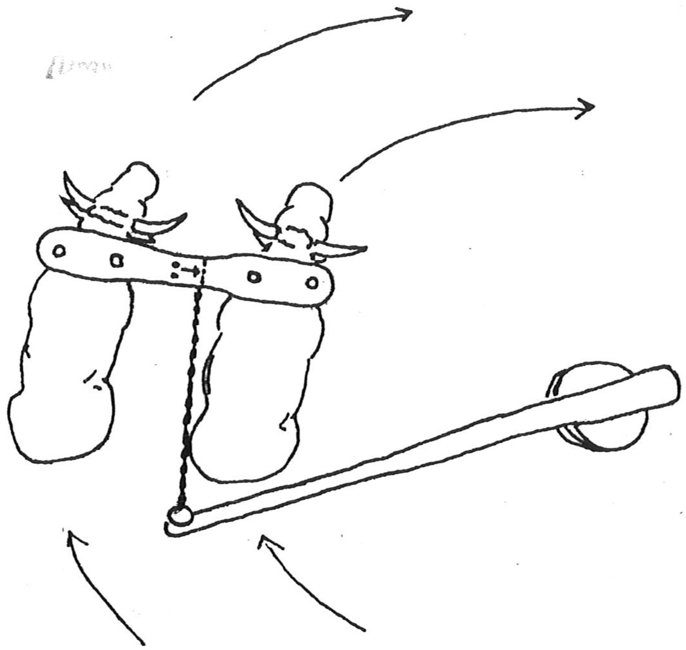

FIGURE 15: ***When working in a circle, the outside animal has to travel much farther and thus do more work unless the hitch-point of the yoke is placed off center to reduce his load.*** *(Drawn by Marcia Keith)*

animals centered at 4 feet apart in a yoke turning a 12-foot sweep, the needed off-set can be calculated approximately by dividing the radius of the circle walked by the outside animal by the radius at the hitch point (14 ft/ 12 ft) and multiplying that factor by the distance on the yoke from its center to the center of the animal, (24 inches x 14/12 = 28 inches). The inside end of the yoke would be reduced accordingly to 20 inches. Since work equals distance times force, the work is equalized by manipulating the force required relative to the distance travelled.[7]

Drop of the Hitch Point

The traditional dropped hitch point yoke has a deep belly and a significant drop. The belly is the distance from where the necks rest in the beam to the bottom of the beam (see Fig. 16). This distance is extended even further by the staple, the iron hitch point to which the ring and chain attach.

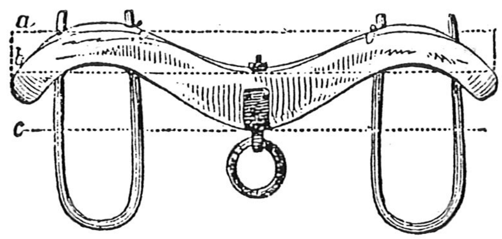

FIGURE 16: ***This old drawing illustrates a yoke with a deep, heavy belly, b to c.*** *(Thomas, 1869:78)*

Two reasons for this depth should be remembered when designing a yoke. First, the belly of the yoke creates a pendulum effect by lowering the yoke's center of gravity. A lower concentration of weight helps stabilize the yoke on the animals, especially when they move without a load. The heavier the belly the more stable the yoke. An iron staple adds to the pendulum effect. The drop across the top of the beam reduces top weight and increases the pendulum effect. Too much drop, however, will reduce the beam's strength by eliminating all the through-grain of the wood.

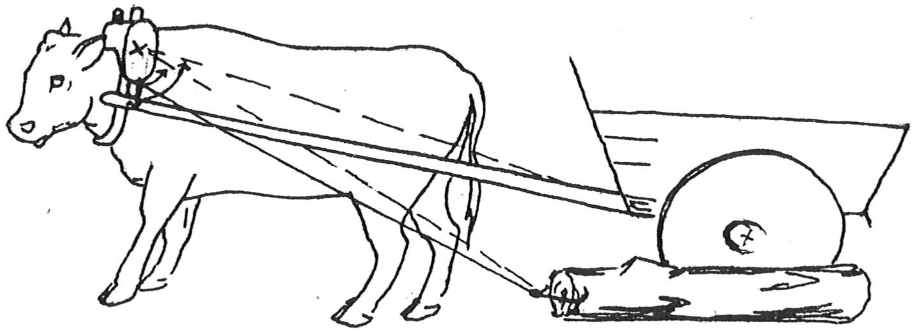

FIGURE 17: ***With a dropped hitch-point yoke, the higher the point of resistance for a given load, the harder the bows will turn into the shoulders.*** *(Drawn by Marcia Keith)*

Second, the drop of the staple to its hitch-point determines the portion of the load which is leveraged onto the bows and shoulders of the team. The lower the hitch-point, the more draft transfers to the shoulders. Usually the drop to the hitch-point in the staple is about 1/3 to 1/2 the depth of the bows when fitted to the team. Thus, most of the force (about 2/3s) is left on the neck seats of the beam as compared to the bows.

The desired drop varies with differing uses. With all dropped hitch-points, the higher the point of resistance in a load, the more the bows will be turned back into the shoulders of the team. For example, a wagon with high wheels has a more horizontal line of traction than does a plow. Thus, if a yoke is designed for use with a more horizontal line of traction, one would expect it to need less drop to the hitch point. A yoke for pulling heavy stoneboats hitched short by this rule would have the greatest drop.

Tradition, however, does not agree. William Bunting points out that a traditional wagon yoke had much more drop than a yoke for pulling a heavy stone boat. He says, "On the cart the shallow-drafted yoke is going to roll back, and on the short-hitched heavy load the deep-drafted yoke is going to prevent lift, and is going to pull their heads down."[8]

This is an area for further study. There appear to be several factors interacting which sometimes have greater importance than the geometry of the yoke and the line of traction. These include the nature of the force required by the task and the desired position of the heads of the pair. Do the greater bursts of force required for the stoneboat suggest too much force being transferred to the bow? Does the smoother and lower draft of the wagon require a deeper hitch point to keep the bows back into the shoulders?

The Staple

The Width of the Staple's Bulb

The ring which connects the yoke and the traction chain rides in the bulb of the staple. The width of the bulb is important. It serves to dampen or limit the rotation of the bows back into the shoulders under a load (see Fig. 18). Thus, it off-sets the drop of the hitch point. The wider it is, front to back, the less force will be transferred to the shoulders through the bows. Perhaps only the best yoke makers understood the significance of bulb width on yoke dynamics. Jochen Welsch of Old Sturbridge Village says, "This is a comparatively modern adaptation -- second half of the 19th century at best. Traditional early yokes generally have only one ring and a narrow bulb just big enough for the ring."

While we do not know for what circumstances the yoke makers widened staple bulbs, it is clear that width limits extremes of rotation. Thus, if you want a deep belly on a yoke for use with a near horizontal line of traction, putting extra width in the bulb of the staple will limit the force transferred to the bows. For staples with wide bulbs, their width seems to have

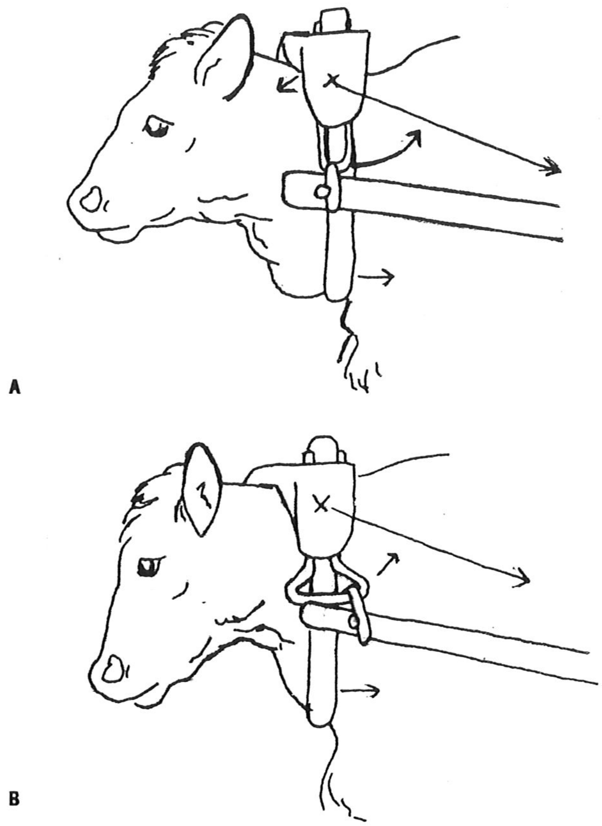

***FIGURE 18:** A wider staple bulb, B, limits the beam's roll and the movement of the bows as the load attempts to straighten the line of draft.* (Drawn by Marcia Keith)

been about half the drop of the hitch point. But there was considerable variation. We have not found discussion of this in the literature. It should be studied more closely.

Offset of the Staple from the Center

Placing the staple in the center of a yoke balances the load between the oxen. While balance is the usual objective, there are circumstances when that is not desirable. If one animal is weaker or to be favored, the staple can be placed off center. Placing it further from the weak animal gives that animal longer leverage and a mechanical advantage. The draft effects can be calculated as the inverse of the ratio of the distances to the center. For example, if the distance from the weak animal to the center is twice the distance from the stronger animal to the center, 2:1; the force required of the weaker animal will be 1/2 that required of the stronger animal (or 1/3 of the total draft). Usually, off-sets would be made in much finer increments such as 16:14. Several contemporary yoke makers have introduced sliding staples for quick adjustment with a wrench. These are common among ox pullers.

Yoke Makers

Robert Boynton, Jr.	*Route 2, Box 174* *Concord, NH 03301*
Ray Ludwig	*552 Old Post Road* *Polland, CT 06085*
Watson Smith	*122 E Street* *N. Grandby, CT*
Jochen Welsch	*PO Box 242* *Hardwick, MA 01037* *Historical work*
Tillers International	*5239 South 24th Street* *Kalamazoo, MI 49002*

Integrating Design Considerations

We have analyzed several factors that should guide the design of a neck yoke with a dropped hitch point. The primary factors are:

- Neck width
- Tasks affecting spacing of the team
- Tasks affecting depth of the hitch point
- Equality of the team

With this information, a yoke can be designed to meet needs effectively.

After considering these factors, it is good to integrate them into a sketch and template, or pattern, before beginning construction. An overhead view can show the planned placement of bow holes, and staple, as well as the length and thickness of the beam. A front view will add the drop of the belly and the staple and show the longitudinal curves of the neck pieces and the expected bow depths. Two cross sections can be helpful. One at the center, or staple, can show detail there and one at the center of a neck seat will give added detail. If elliptical curves are hard to find, Tillers' full-sized patterns include several optional ellipse rotations.

Actual size templates of half of the overhead view and half of the front view are good guides for construction. They can be flipped for tracing a symmetrical opposing side. The front template can be aligned on the beam stock with the help of a reference line through the neck seats and noting distances from the top and belly of the beam at the center point will help align the template on the beam stock.

After careful planning, building a yoke is more fun and productive.

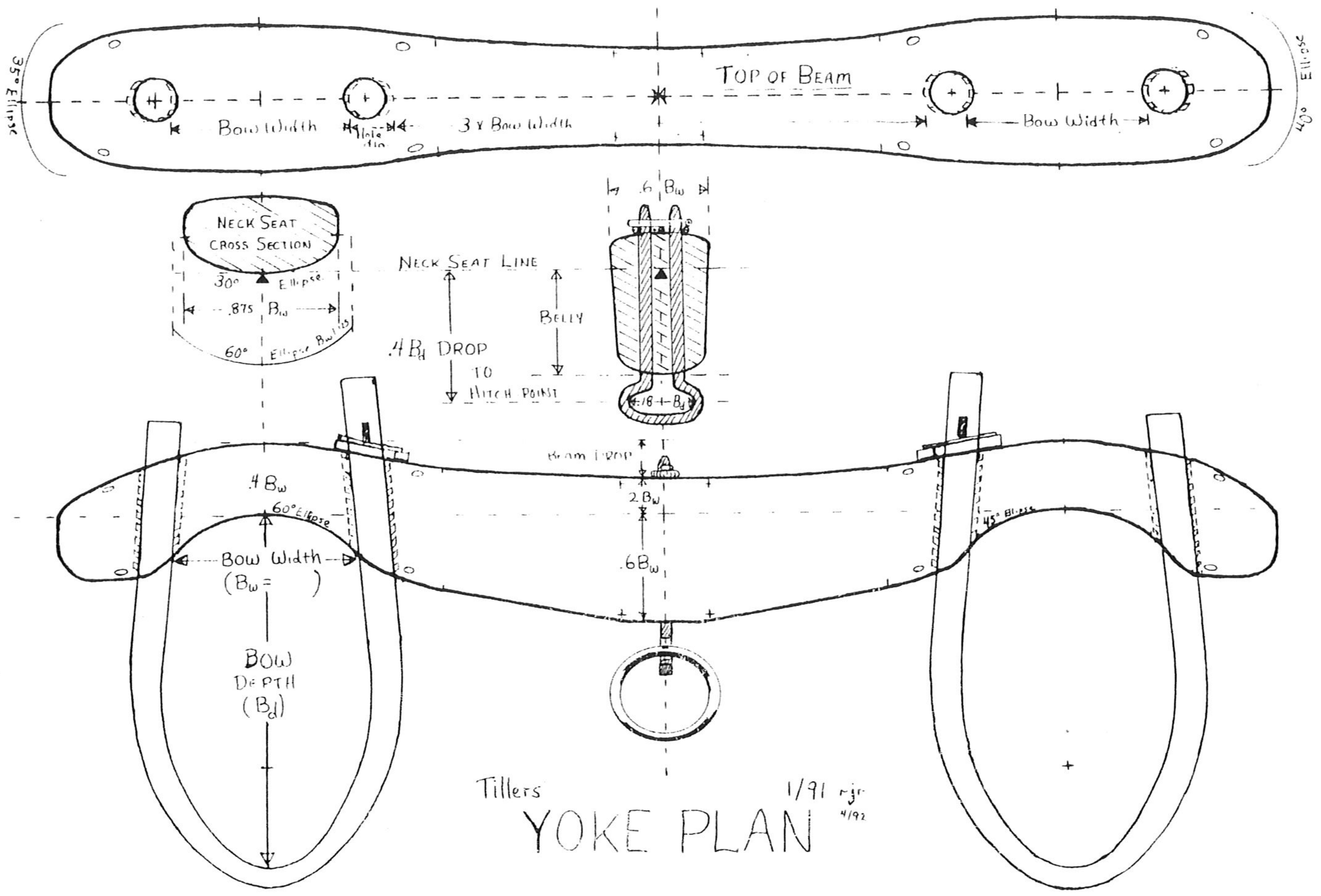

FIGURE 19:: Sketches of the overhead and front views of a planned yoke help integrate the fitting factors. Tillers has full-sized patterns in 1 inch (2.5cm) increments from 4 to 10 inches (10cm to 30cm). ***(Drawn by Roosenberg)***

Conclusion

This **Tech*Guide*** attempts to stretch the understanding of yoke dynamics. While there is more to be learned, effective yokes can readily be built with the information discussed here. Tillers' forthcoming TechGuide on Making Dropped Hitch Neck Yokes should provide helpful tips on means to capture the advantages of traditions with available skills, tools, and materials.

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Ordering Information

Price; $3.00 Plus mailing (US $3.00, other $4.00)
Full size yoke plans and templates available, bow-width sizes 4" to 14"—Please phone for prices

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Notes

1. William Bunting, Robert Porter, and Rolf Minhorst drew our attention to and helped clarify this interaction between ox anatomy and yoke dynamics.

2. Drew Conroy points out that too thick of bow stock would also interfere with the movement of the shoulder.

3. The spacing of keeper or pin holes in a bow are recommended to be placed at 1" intervals by Robert J. Boynton, Jr. to allow any adjustment with washers (or spacers) of assorted thicknesses up to 1 inch. He suggests the lowest hole can be marked with the bow touching the bottom of the neck when the yoke in a forward position. At Tillers, we generally use up to 2 inches of spacers which permits the use of fewer pin holes.

4. In New England, the most important part of a yoke -- the seat in which the neck rests and works -- sometimes is called the "neck piece." For international purposes, this does not seem very intuitively descriptive. If anyone knows alternate terms or wants to nominate a better candidate, Tillers would love to hear from you. Possibilities include "neck seat" and "neck cradle."

5. Drew Conroy notes, however, that the strongest competition oxen always push upward as well as forward when pulling a very heavy load.

6. R.P. Gupta, in a visit to Tillers, pointed out the significance of this problem. Others suggest switching sides for the oxen, although this frequently requires retraining especially of turn commands.

7. Steve Belkoff suggests a more universal formula.

r_o = *radius for the path of the outside animal (14 feet)*
r_i = *radius for the path of the inside animal (10 feet)*
x = *distance from the outside animal to the hitching point*
p = *optimal hitching point*
F_o = *force required of the outside animal*
F_i = *force required of the inside animal*
W = *work (known to equal force x distance)*
l = *length between centers of the yoke*

"The work of the outside animal is $W_o = F_o \cdot r_o \cdot 2\pi$ *... and the work of the inside animal is* $W_i = F_i \cdot r_i \cdot 2\pi$. *We want* $W_o = W_i$, *so after canceling* 2π, $F_o r_o = F_i r_i$ *(equation 1).*

"To find the relationship between F_o *and* F_i, *look at the hitching point (force R) as a fulcrum and balance the moments about that point, you get:* $F_o X = F_i(l-x)$, *or* $F_o/F_i = (l-x)/x$ *(equation 2).*

"If we substitute equation 1 into equation 2, we get: $r_i/r_o = (l-x)/x$ *Consolidate terms and solve for x to get,*

$x = l/(1 + r_i/r_o)$.

"For your example, the optimal distance from the center of the outside ox to the optimal hitching point "p" is

$x = 4'/(1 + 10'/14'), = 28''$.

8. Personal correspondence from William Bunting, January, 1991.